4(e). The use of a simple L-section matching network at the output resulted in the circuit configuration of Fig. 5. This oscillator was constructed and yielded a stable oscillation at 1.03 GHz with a measured power output of 23 mW (36-percent efficiency), which is in good agreement with the predicted performance.

IV. Conclusion

In the design procedure presented here, no modeling or characterization of the transistor is required. Instead, a simple experimental amplifier optimization yields results which can be directly utilized in the calculation of six basic oscillator topologies, each delivering the same power. This procedure should be applicable to any two-port active device, provided that the effects of harmonic terminations are not of first-order importance, which is almost always the case with bipolar transistor and FET designs at microwave frequencies [4].

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Microwave Helix Waveguide Absorption Cell for Passive Frequency Standard

JEAN-CLAUDE MOLLIER AND MICHELLE VALENTIN

***Abstract*—A new closed absorption cell, which has been developed for a passive frequency standard, is described. This cell is made from a cylindrical quartz tube with copper wire wound around it. For the limiting case of the zero pitch helix, Maxwell's equations are graphically solved, which show that the cell is operating like a monomode waveguide at 23.8 GHz, the frequency of interest, and can be used from 10 to 100 GHz with few modifications.**

***Indexing Terms*—Microwave absorbtion cell, Helix waveguide, Mode filter, Passive frequency standard.**

A device was built using a stripline oscillator at 468 MHz, frequency-locked to the 3–3 ammonia line after a one-step frequency multiplication [1]. In order to ensure the stability of the absorption signal over a long period of time, with low-pressure gas (from 0.7 to 1 Pa) and low-excitation power (1 mW), a carefully designed cell is needed: the walls must be made from inert material in order to avoid reaction with ammonia gas and rapid disappearance of the signal. The cell must behave as a nonresonant structure, with small vibrations sensitivity and reduced losses. After testing many types of absorption cells, a unique closed cell has been developed, which behaves like a monomode helix waveguide [2],[3].

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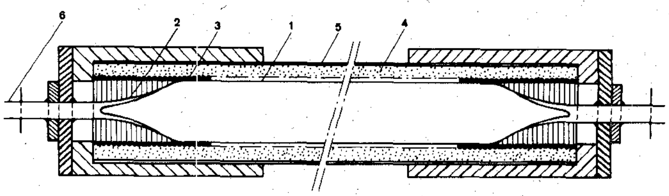

Fig. 1. Longitudinal cutaway of the helix cell. 1—sealed quartz tube. 2—transitions: guide-emitter, guide-detector. 3—closely wound turns of insulated copper. 4—flexible carbon polyurethane foam. 5—copper cylinder. 6—waveguide.

A longitudinal cutaway is shown in Fig. 1. The cell is made from a cylindrical fused-quartz tube, whose ends are tapered to a point providing a smooth transition and a degree of matching with the K-band metallic waveguides. The tube has inner and outer diameters of 23 and 25 mm, respectively. Insulated copper wire is wound on the tube so as to make a helix of very small pitch (closely wound turns). In order to reduce mode conversion-reconversion effects and external radiation, the helix is surrounded by a lossy medium (flexible carbon-loaded polyurethane foam) and by a coaxial copper shield which makes the device insensitive to shocks. The helix cell is inserted between two circular horns which are connected, through K-band rectangular waveguides, the one to the multiplier output, the other one to a matched detector.

The round wire helix covered by the lossy jacket provides a low attenuation of the TE_{on} propagation mode in cylindrical waveguide and a very large attenuation for all other modes: the real part of the propagation constant is of the order of 2×10^{-2} dB/m for the TE_{01} mode and is varying from 10 to 200 dB/m for the first hybrid modes.

This filtering efficiency has been verified experimentally by studying the resonant modes of resonators realized from a section of oversized helix waveguide and from a section of circular metallic pipe with the same length and diameter [4]. The helix waveguide with dielectric coating is effectively a good mode filter.

The circular metallic guide with inner dielectric coating is an asymptotic case of the type of guide under consideration for the propagation of TE_{on} modes. Special attention is then given here to the limiting case of a zero pitch helix surrounding the quartz tube. Maxwell's equations are solved by following the procedure set up by Stratton [5] for the classical cylindrical waveguide boundary problem. The fields confined into the tube are found by assuming that the helical sheath is perfectly conducting in the transverse direction and does not conduct in the longitudinal one. The application of boundary conditions for E and H fields gives the two following equations:

$$\frac{J_1(b/ax_1)}{x_1 J_0(b/ax_1)} = \frac{1}{x_2}\cdot\frac{J_1(x_2)Y_1(b/ax_2)-J_1(b/ax_2)Y_1(x_2)}{J_1(x_2)Y_0(b/ax_2)-J_0(b/ax_2)Y_1(x_2)} \tag{1}$$

$$x_2^2 - x_1^2 = \left(\frac{2\pi a}{\lambda_0}\right)^2\cdot(\epsilon_r - 1) \tag{2}$$

$$x_1^2 = a^2(\omega^2\mu_0\epsilon_0 - \beta^2)$$

$$x_2^2 = a^2(\omega^2\mu_0\epsilon_0\epsilon_r - \beta^2) \tag{3}$$

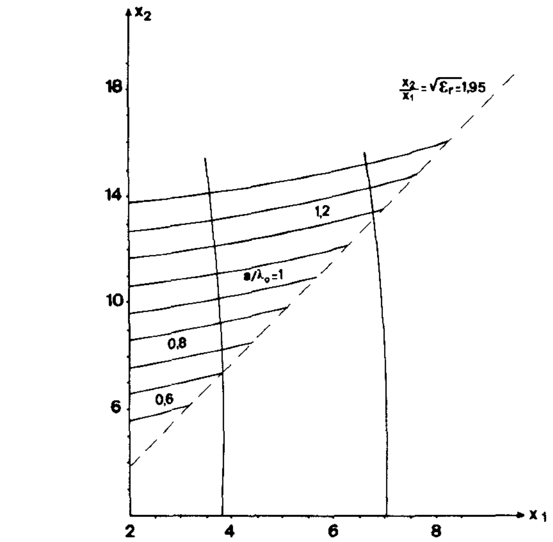

Fig 2 Graphical resolution for the propagation constant β. Experimental conditions: $a/\lambda_0 = 1$

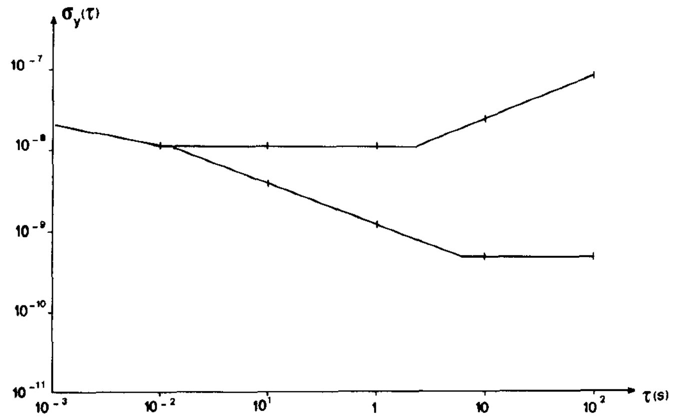

Fig. 3. Allan variance $\sigma_y(\tau)$ for free and frequency locked oscillator at 468 MHz.

where β is the unknown propagation constant, a and b are outer and inner radii of the quartz tube, and ϵ_r is the tube permittivity.

Equations (1) and (2) may be solved graphically. In Fig. 2, two families of curves are plotted: a) nearly vertical curves give the values of x_1 and x_2 which obey to (1); and b) the sections of hyperbolas are the loci of a point whose coordinates (x_1, x_2) verify (2), depending on the ratio a/λ_0.

With the numerical values $\epsilon_r = 3.78$ and $b/a = 0.92$, only the TE_{01} mode can propagate in that guide if

$$0.6 < a/\lambda_0 < 1.07.$$

With an outer quartz tube radius of 12.5 mm, the cutoff frequency of the two first modes TE_{01} and TE_{02} are 14.4 and 25.8 GHz, respectively. Thus, in the experimental conditions where $a/\lambda_0 \simeq 1$, the cell behaves like a monomode helix waveguide for the TE_{01} mode with phase velocity of the order of 3.75×10^8 m/s.

A plot of the frequency stability obtained for the frequency-locked oscillator with the closed ammonia cell described above is shown in Fig. 3. These data were computed using the so-called Allan variance for averaging times varying from 10 ms to 300 s; the frequency drift has not been removed. The flicker floor is found at 5×10^{-10} for τ less than a few minutes.

Fluctuations of the ammonia molecules excitation power limit the long term stability to 8×10^{-10} over a day at this time.

Conclusion

A closed absorption cell has been developed for the use in two fundamental areas: passive frequency standards and spectroscopy. The good performances of that type of cell as a monomode waveguide with small insertion losses make it very attractive for microwave frequencies (from 10 to 100 GHz).

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94-GHz 4-Port *E*-Plane Junction Circulator

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***Abstract*—A 4-port junction circulator for use in 94-GHz *E*-plane integrated circuits is investigated. The design incorporates an *E*-plane *X*-junction of standard metal waveguides with a single ferrite disk on one of the narrow walls of the junction plus a metal plunger extending into the junction from the opposite side. The plunger is used to tune the $n = 0$ mode to the circulator center frequency and additionally can be used to tune the circulator center frequency over several gigahertz without critically degrading circulator performance. Minimum insertion loss of 0.65 dB was typical in a series of 12 plunger-tuned circulators with adjacent port isolation better than 20 dB, and crossport isolation better than 15 dB over nearly a 1-GHz bandwidth.**

I. Introduction

Printed *E*-plane integration of millimeter-wave circuits has made great progress recently [1] and *Y*-junction circulators have been developed especially to serve in *E*-plane circuits [2]. In this paper, the 4-port circulator is presented as another variant of the *E*-plane junction circulator. 4-port circulators may be employed as a transmit–receive duplexer with one of the ports terminated in a matched load to absorb the power reflected from the receiver-protection circuit during transmission. This is not the only useful application of the 4-port circulator, as other applications have been identified, e.g., in power-combining, and will be reported later.

At present, *E*-plane 4-port circulators seem to have not found widespread use, probably due to the limited bandwidth that has restricted use of *E*-plane *Y*-junction circulators. Consequently, only two publications on the subject have been found [3],[4], describing devices for high average power applications, where *E*-plane circulators have a clear advantage.