COMPONENTS FOR MICROWAVE INTEGRATED CIRCUITS WITH EVANESCENT MODE RESONATORS

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Abstract

The electrical performance of active microwave components for radio link systems is described, which have been realized utilizing evanescent mode resonators. This waveguide-below-cutoff technique is shown to be an alternative to the techniques established till now.

Introduction

A few years ago, Craven[1] presented a new type of passive integrated circuitry utilizing evanescent mode resonators. In this technique inductance is represented by short sections of rectangular waveguide below cut-off, capacitance by obstacles in the waveguide such as a capacitive screw or a thin sheet of dielectric. Thus resonators of very high unloaded Q-factor can be formed called evanescent mode resonators. Active and nonlinear elements are easily integrated, as their electronic capacitances can form a part of the resonant structure.
In [1] and in associated papers preferably passive components for the lower GHz-range have been developed. These investigations seem to be complete. But few work, however, deals with active components: a varactor diode upconverter and a Gunn oscillator have been described but not systematically investigated. Hence their performance is not optimum. Concerning the construction of other active components only guidelines have been given. Hence this work was devoted to demonstrating the applicability and superiority of the waveguide-below-cutoff technique for high quality microwave systems such as microwave radio links and satellite systems.

Prototype Circuit

For application purposes we have chosen radio link system components utilizing both FM and PSK. In order to achieve a high degree of standardization a prototype oscillator circuit has been developed which can be used for local oscillators, injection-locked-amplifiers for both FM and PSK signals, voltage-controlled oscillators for use in a phase-locked loop for amplification or frequency stabilization, and cavity stabilized oscillators. The circuit is suitable for Impatt diodes and Gunn elements. The prototype circuit can further be used as phase modulator with pin-diode for performing PSK.

The circuit is sketched in fig.1. The resonant diode mount is formed by the evanescent mode waveguide 2, the power is extracted through a propagating waveguide 1. Both waveguides are coupled by a narrow slot in their common wall. (In an integrated circuit system the propagating waveguide 1 will be replaced by the component subsequent to the oscillator, e.g. by a filter or by a circulator, which are realized with evanescent mode resonators, too.) Resonance conditions are established only after introduction of the active device D, which stores predominantly electric energy and thereby establishes the necessary balance between the time average amounts of electric and magnetic stored energies. The resonance structure is thus limited to the volume immediately surrounding the active device. The screws can fulfill either of two operations: They can tune the oscillation frequency if they are located in the vicinity of the active device; otherwise they form additional resonators as is important e.g., if one wants to increase the locking bandwidth of an injection-locked amplifier for FM signals by reactance compensation. The load is matched via the dimensions of the slot, which but weakly affect frequency.

Basic Features

The significant features of the technique are the following: The individual elements of equivalent circuits approximate lumped elements in a large frequency range. There is no periodic relationship between reactance and frequency as in other distributed constant networks, for progressive waves are not supported if the frequency does not exceed the cut-off frequency of the host waveguide. In a frequency range, where it does, however, poles and zeros of network functions will in general not be harmonic to the working frequency and hence will not degrade the electrical performace.- Another advantage of the new technique is, that a given equivalent circuit can easily be realized without introducing undesirable parasitic elements as e.g.

in normal waveguide technique. This is due to the lumped character of both the inductances and capacitances. Both elements concentrate their associated fields in a small and well-defined volume. Thus a high degree of predictability is achieved when special components are realized. - Further advantages are a substantial reduction in size, weight, and cost of both passive and active microwave components. The technique does, of course, not compete with existing thin and thick film techniques in this respect, it leads, however, to superior electrical performance.

Experimental results presented below will confirm that the waveguide-below-cutoff technique is superior to coaxial or to normal waveguide technique in the sense of cost, size, and weight of realized components. More remarkable is the far better electrical performance, which is mainly due to the lumped character of the network elements. In camparison with thin and thick film techniques the waveguide-below-cut-off approach leads to superior electrical performance of many active components, too. Hence the technique is believed to represent a remarkable alternative to the techniques established till now. It should be applicable up to frequencies in the lower millimeterwave region (30-40GHz).

Concluding this chapter its significant features shall be summarized:

- lumped element character of networks,
- high degree of predictability,
- lack of parasitic elements,
- small circuit losses,
- feasability of integrating passive and active components,
- remarkably simple microwave networks,
- substantial reduction in size, weight, and cost.

Applications

Modifying the prototype circuit some oscillator components for the 7, 11, and 15 GHz bands have been developed. Their electrical performance is briefly described in the following.

Injection-locked amplifier: Using a Gunn element a relative locking band-width of 20% could be achieved at a gain of 10 dB with an output power variation of less than ± 0.5 dB. In case of 20 dB gain, the locking bandwidth exceeded 10%. A typical curve is given in fig.2. Phase linearity and AM to PM conversion were sufficient over a frequency range of 7%.
The locking bandwidth of an Impatt diode oscillator was smaller due to its higher Q-factor. At 20 dB gain a 200 MHz-locking bandwidth could be measured in the 7 GHz band. The amplifier could be tuned by one screw over a 10% frequency range with a locking bandwidth not less than 150 MHz.

Mechanically tunable oscillator: The oscillation frequency can be tuned by one screw over 18% bandwidth with the output power being constant within ± 0.5 dB (see fig.3!). Over a relative frequency range of 15% the output power ripple is even less than ± 0.25 dB.

Electronically tunable oscillator: Replacing one screw of the prototype circuit by a varactor diode yielded a tuning range o 15% with an output power ripple less than ± 0.5 dB. The power loss in the varactor diode was 0.5 to 1 dB. Typical tuning curves are given in fig.4

Mechanically and electronically tunable oscillator: The oscillation frequency could be mechanically tuned over a relative bandwidth of 13% (output power constant within ± 0.5 dB) and additionally by a varactor diode over 5% (additional power ripple less than ± 0.25 dB). Inserting another varactor diode for FM purposes yielded tuning ranges of 15% (meachanically), and of 5% and 30 MHz, respectively, for the two varactor diodes. The 30 MHz tuning range allowed performing linear FM.

Cavity stabilized oscillator: The evanescent mode resonator 2 of fig.1 had been directly coupled to a transmission cavity, in order to arrive at a low noise, highly stable local oscillator. In this structure the half-wavelength-long intermediate transmission line can be omitted. Thus no mode jumping problems occur (as is the case in all other cavity stabilized oscillators reported till now). Then a damping resistor in the coupling line can be omitted leading to enhanced output power. The compound oscillator structure showed a loaded Q-factor of 6000 at the sacrifice of less than 2 dB power (unloaded Q-factor of the TE_{012}-type cavity being 27000 at 15 GHz). Over a tuning band width of 700 MHz the output power was constant within ± 0.5 dB. The FM-noise was less than 0.1 Hz measured in a 100 Hz bandwidth. By mechanically compensating the frequency drift with temperature change, a frequency stability of $1\cdot10^{-5}$ could be achieved from -30 to +50°C.

A reflection cavity stabilized oscillator is shown in fig.5. 1 is the bias port of the active device, 2 that of a varactor diode. The evanescent mode resonator 3 is slot-coupled to both load and TE_{011}-mode cavity 4. The tuning range was limited to 800 MHz at a midband frequency of 15 GHz by the mechanical cavity tuning. The electronic tuning range amounted to 10 MHz over the whole band.

Multi-device oscillator: The power of two active devices could easily be summed up.

Phase modulators with pin-diode: Utilizing the same prototype circuit a reflection-type phase modulator with pin-diode was developed. A severe restriction in the performance of phase modulators is their narrow bandwidth of typically 1%, which is defined with respect to a tolerable deviation from the desired phase shift (e.g. ± 4° in case of an 180°-modulator) and to a tolerable imbalance in the reflection coefficients of the two states (less than 0.05). The evanescent mode modulator inherently shows broad band performance: the tuning bandwidth amounted to 10% for an insertion loss of 0.5 dB and 1 ns switching times at a midband frequency of 14.9 GHz. Phase shift error $\Delta\varphi$ and imbalance ΔR of the reflection coefficients are shown versus frequency in fig.6.

Finally a transmission-type phase modulator shall be mentioned. It greatly differs from hitherto existing devices in that it needs only one pin-diode, which is part of a waveguide-below-cutoff bandpass filter. Switching the pin-diode from one state to the other means shifting the pass-band of the filter, thus performing a phase shift of the transmission coefficient. A 90° phase shift could be achieved in a bandwidth exceeding 10% with 0.5 dB insertion loss.

Conclusions

Concluding the relative importance of the described technique is summarized. It is superior to coaxial or to normal waveguide technique in the sense of cost, size, and weigt of realized components. More remarkable is the far better electrical performance, which is mainly due to the lumped character of the network elements. In comparison with thin and thick film techniques the waveguide-below-cut-off approach leads to superior electrical performance of many active components, too. Hence the technique is believed to represent a remarkable alternative to the techniques established till now. It should be applicable up to frequencies in the lower millimeterwave region (30-40 GHz).

Acknowledgement

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Reference

1. G. Craven, "Waveguide below cutoff: A new type of microwave integrated circuit", Microwave Journal, vol. 13, p. 51, Aug. 1970.

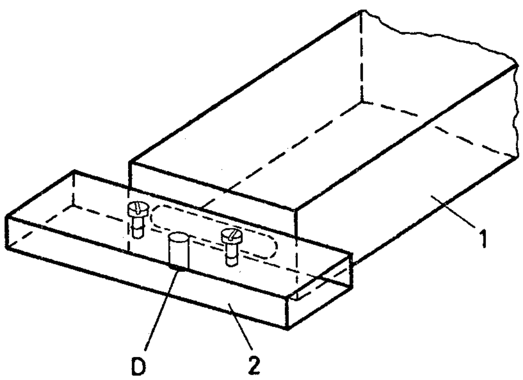

Fig.1 Prototype oscillator circuit

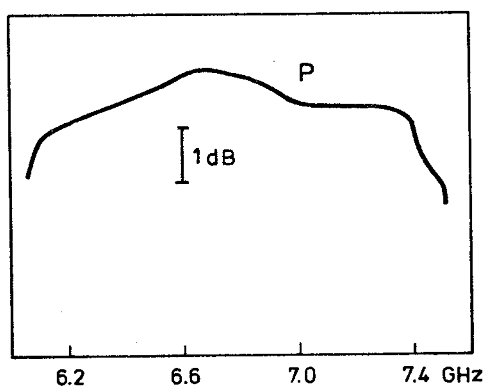

Fig.3 Output power P of mechanically tuned Gunn oscillator

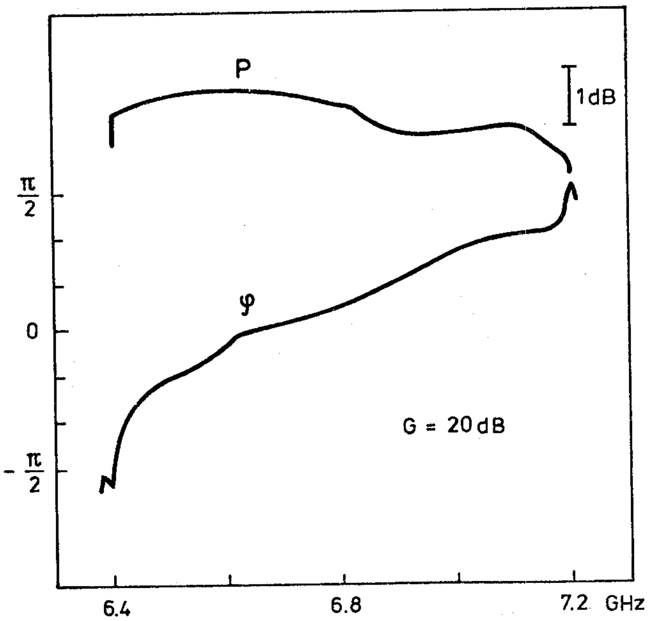

Fig.2 Output power P and phase of injection-locked Gunn oscillator

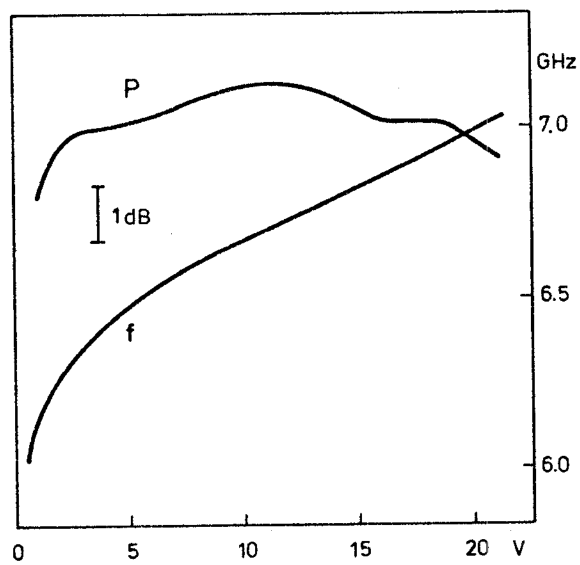

Fig.4 Output power P and frequency f of electronically tuned Gunn oscillator

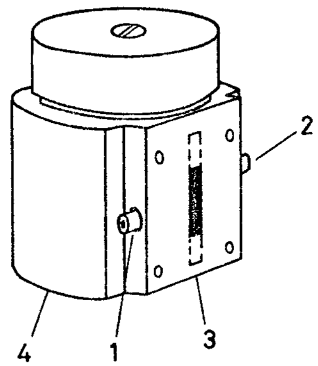

Fig.5 Reflection cavity stabilized oscillator

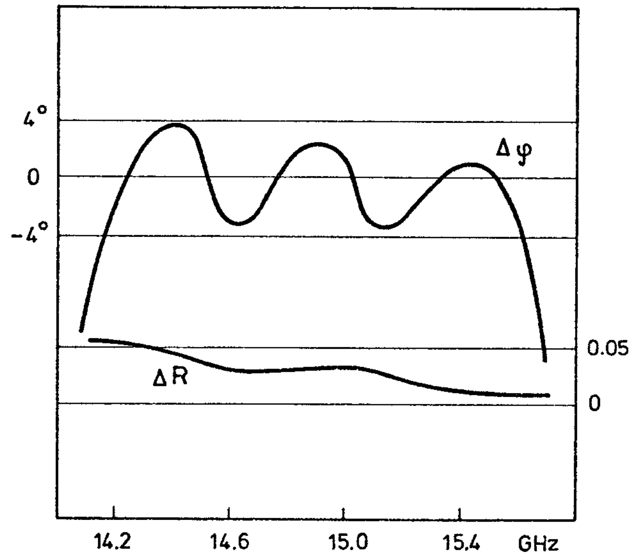

Fig.6 Phase shift error $\Delta\varphi$ and imbalance ΔR of the reflection coefficients of a phase modulator