"24 GHZ LOW-COST DOPPLER SENSOR WITH FUNDAMENTAL-FREQUENCY GAAS PSEUDOMORPHIC HEMT OSCILLATOR STABILIZED BY DIELECTRIC RESONATOR OPERATING IN HIGHER-ORDER MODE"

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ABSTRACT

24 GHz fundamental-frequency microwave oscillators using low-cost packaged HEMTs and a dielectric resonator in a higher-order mode are reported. From the very high quality factor of the resonator-mode, excellent phase noise (-95 dBc/Hz at 100 kHz offset) and a good temperature stability (+9ppm/K) are achieved. The output power is about +10 dBm. By adding a demodulator diode and a patch antenna, a high-performance low-cost Doppler sensor for speed over ground measurements has been built.

INTRODUCTION

By the increasing use of automated vehicle-control and navigation systems the interest in high-performance, low-cost Doppler sensors for precise measurements of speed over ground has been stimulated [1]. For these and similar applications, Doppler sensors operating in the 24 GHz band provide high sensitivity and excellent reliability at low cost. Cost-effective dielectric resonator oscillators (DROs) at 24 GHz have been realized as harmonic-mode oscillators so far [2], but they have significant unwanted spurious output at 12 GHz. Recent advances in High Electron Mobility Transistors (HEMTs) make the employment of low-cost packaged HEMTs for operation at millimeter wave frequencies possible [3]. Thus, fundamental-frequency DRO operation at 24 GHz is within reach now.

PRINCIPLES OF DRO OPERATION

The key component in a Doppler radar sensor is the microwave oscillator. DROs are known to be temperature stable, reliable and have low phase noise. This good technical performance, the low price and the compact dimensions made them popular. With respect to the feedback network, series or parallel, two types of transistor DROs can be distinguished. The reflection-type DRO,

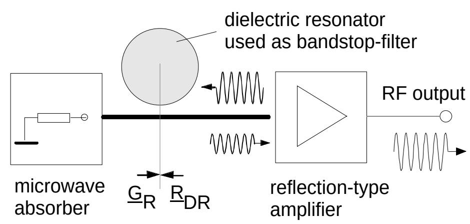

Fig. 1: Reflection-type DRO.

which uses the dielectric resonator as a bandstop-filter, is of the series feedback type (Fig. 1). A transmission-type DRO has a parallel feedback network with bandpass characteristics (Fig. 2).

The reflection amplifier in Fig. 1 is in principle a transistor with potential instability ($S_{11}=G_R>1$). Feedback is established by a dielectric resonator ($\underline{R}_{DR}$) and oscillation occurs, when the condition $\underline{G}_R \cdot \underline{R}_{DR} = 1$ is satisfied at the operating frequency. The main problem is, that the DRO must be stable for all frequencies outside the operating frequency, otherwise unfavourable conditions may cause unintended oscillation (mode jumping). With packaged low-cost microwave FETs this demand is rather difficult to achieve.

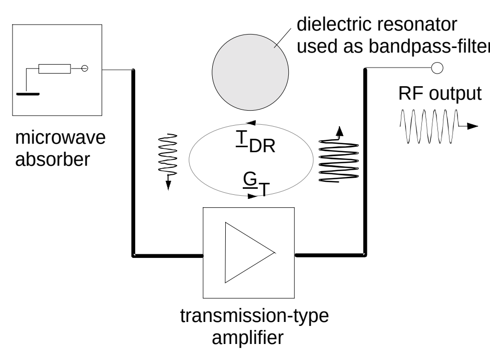

Fig. 2: Transmission-type DRO.

In contrast, a transmission-type DRO makes use of a stable amplifier ($S_{21}=G_T>1$). Mode jumping cannot occur, because the parallel feedback path established by means of a dielectric resonator ($\underline{T}_{DR}$) is effective only at the operating frequency. In this case the oscillation condition is $\underline{G}_T \cdot \underline{T}_{DR} = 1$.

DIELECTRIC RESONATOR FEEDBACK-FILTER

For DROs the loaded quality factor of the frequency determining feedback-filter is essential for phase noise behavior and temperature stability [4]. The small dimensions of dielectric resonators for frequencies beyond 20 GHz, even when using lower permittivity materials, lead to ineffective coupling to a microstrip line [5]. Dielectric, conductor and radiation losses become dominant effects. Therefore, dielectric resonators - traditionally using the $TE_{01\delta}$-mode - show a significant degradation in quality factor. At the same time, the available gain of transistors declines rapidly making it impossible to compensate the degradation with weaker coupling of the resonator. Ceramic materials with higher quality factors are under constant development [6], but are more expensive than the standard materials. A cost-effective alternative is the utilization of higher-order modes of a standard dielectric resonator. The resonant modes in dielectric resonators have been investtigated comprehensively [7]. Nevertheless, higher-order modes are rarely used in practice, with the exception of Whispering-Gallery modes, which have been used recently at millimeterwave frequencies [8].

Suitable resonator to microstrip coupling configurations for excitation of TE- and TM-modes are shown in Fig. 3 together with the part of the magnetic field, which is important for the coupling. For the excitation of a TM-mode the resonator has to be brought in upright position.

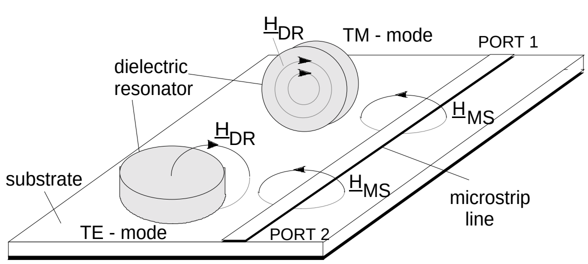

Fig. 3: Microstrip structure for TE- and TM-mode excitation.

The loaded quality factors of two different dielectric resonators (Tab. 1) have been investigated experimentally in a bandstop- and bandpass-filter structure on RT/Duroid 5880 (ε_r=2.2, h=0.25mm, w(50Ω)=0.9mm): DR1 is operating in fundamental mode $TE_{01\delta}$ and DR2, with the $TE_{01\delta}$-mode at 12 GHz, has a strong higher-order TM-mode resonance at 24 GHz. This sharp resonance line, which has been identified as the $TM_{021+\delta}$-mode, turned out to be ideally suited for the stabilization of a DRO. The applied mode identification methods will be explained in the next paragraph. Fig. 4 shows the measurement-setup for a bandstop- and a bandpass-filter in microstrip-technology. Typical measured S11 and S21 resonance curves are plotted in Fig 5. From these S11 and S21 curves, the loaded quality factors Q_L for various typical coupling factors have been calculated. For each data point in Tab. 2 the horizontal and vertical position of the DR has been optimized for maximum Q_L.

DR	mode used	D [mm]	h [mm]	ε_r	$Q_0 \cdot f$ [GHz]	material
1	$TE_{01\delta}$	2.7	1.1	29	$100 \cdot 10^3$	Ba(Zr,Zn,Ta)O_3
2	$TM_{021+\delta}$	4.9	2.0	38	$50 \cdot 10^3$	(Zr,Sn)TiO_4

Tab. 1: Data of investigated dielectric resonators [9][10].

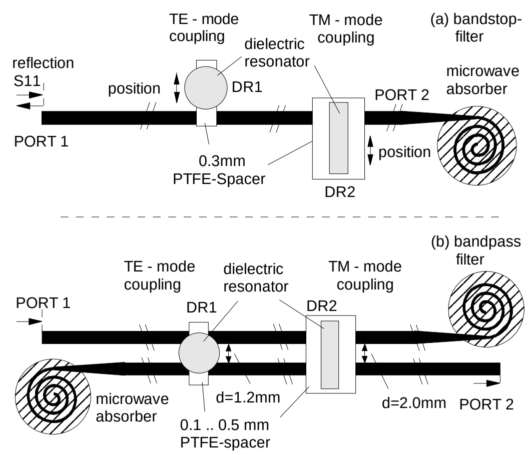

Fig. 4: Measurement-setup: (a) bandstop-, (b) bandpass-filter.

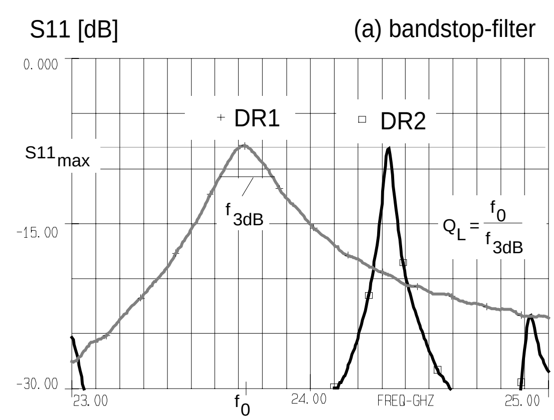

Fig. 5a: Measured resonance curves: bandstop-filter

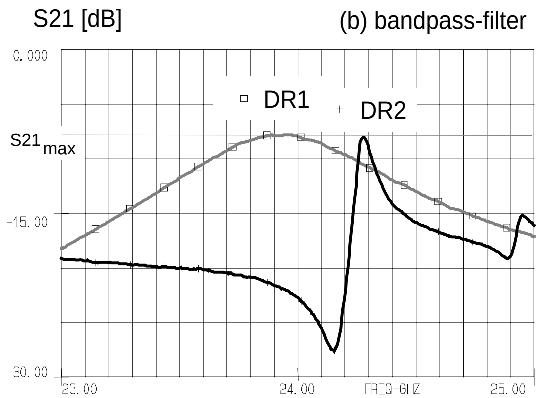

Fig. 5b: Measured resonance curves: bandpass-filter.

$S11_{max}$ [dB], (a) bandstop-filter	- 4	- 6	-8	-10
Q_L ($TE_{01\delta}$)	51	58	95	128
Q_L ($TM_{021+\delta}$)	565	640	675	810
$S21_{max}$ [dB], (b) bandpass-filter	- 6	-7	-8	-10
Q_L ($TE_{01\delta}$)	20	--	35	42
Q_L ($TM_{021+\delta}$)	190	300	340	--

Tab. 2: Measured Q_L: (a) bandstop- (b) bandpass-filter.

The results demonstrate, that the loaded Q-factor can be improved about one order of magnitude by using higher-order modes instead of the traditionally used $TE_{01\delta}$ -mode. This leads to remarkable cost savings because one can use a dielectric resonator, such as DR2, made from standard material instead of expensive high-Q materials. Furthermore the increased size of DR2 leads to easier handling and mounting of the resonator.

MODE IDENTIFICATION

In common literature [7] the modes of a dielectric resonator are denoted by indices m,n,p+δ, which correspond to the order of the mode in cylindrical coordinates φ, ρ and z, respectively. The index +δ indicates, that a part of the field in z-direction is outside the resonator. Modes which have a φ dependence (m≠0) are the so-called hybrid modes $HE_{mnp+\delta}$. For the special case of axial symmetry (m=0) only a transverse electric or magnetic field is existing, these modes are known as $TE_{0np+\delta}$ and $TM_{0np+\delta}$-modes.

To identify the mode corresponding to the resonance of DR2 at 24 GHz (see Tab. 1) the indices m,n,p must be determined: Due to the axial symmetry of the resonator, hybrid modes consist of mixed mode patterns (degeneracy). By breaking this symmetry, the resonance frequencies corresponding to these wave patterns become different. By cutting the edge of the DR, it was possible to split several resonance lines, which are thus identified as hybrid modes. Fig. 6 shows the transmission (S21) from Port1 to Port2, when DR2 is employed in the measurement setup of Fig. 4a (without the absorber). The solid and dashed lines are the curves with and without cutting the edge of the resonator, respectively.

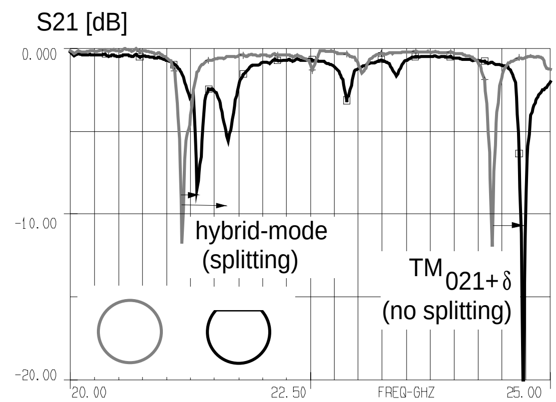

Fig. 6: Cutting the edge of the dielectric resonator (DR2) leads to splitting of hybrid modes.

Since splitting could not be observed for the mode used in the oscillator, we conclude that m=0. By drilling a hole in the axis of the resonator - and even when inserting a piece of wire into this hole - the mode was practically not affected. Therefore, the electrical field has a minimum at the axis of the resonator [7]. Consequently n has to be an even number. From the resonator dimensions only n = 2 seems to be reasonable. The last mode number (p) is difficult to determine in a qualitative manner, but there are a lot of evidences indicating that p=1. Therefore the 24 GHz resonance line of DR2 is the $TM_{021+\delta}$-mode. The identification of the mode will be confirmed by finite-element calculations in future work.

24 GHZ TRANSMISSION-TYPE DRO

A selection of commercially available low-cost transistors has been investigated for use in a DRO at 24 GHz. Because of the higher gain, HEMTs are a better choice than MESFETs. By using a bonded HEMT chip for a reflection-type and a packaged HEMT for a transmission-type oscillator, two fundamental-frequency oscillators at 24 GHz have been realized in microstrip hybrid technology. For both circuits the CFY67, which is a pseudomorphic HEMT [11] is very suitable. The layout-scheme of the transmission-type DRO, which has been etched on 0.25mm thick RT/Duroid 5880 is shown in Fig. 7.

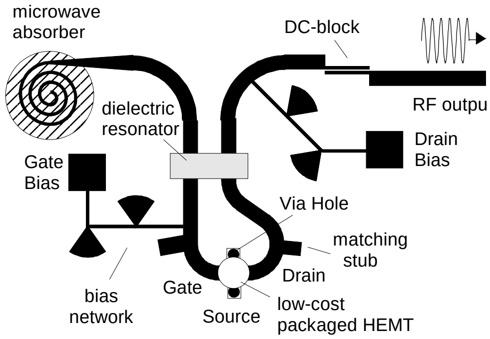

Fig. 7: Microstrip-Layout 24 GHz DRO.

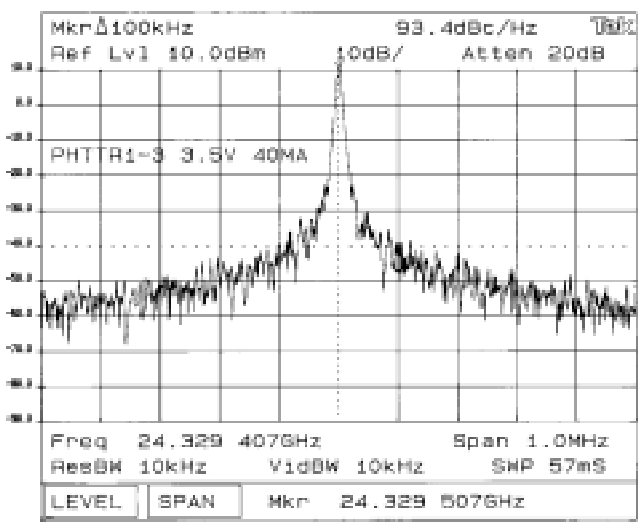

Fig. 8: Typical DRO frequency spectrum.

By use of the higher-order mode of DR2 (see Tab. 1), the oscillator shows excellent phase noise performance (about -95dBc/Hz at 100kHz offset) and temperature stability (max. +9ppm/K from - 40 .. + 100 °C for a resonator with TC=+8ppm/K). The available output power is about +10dBm. A typical frequency spectrum is plotted in Fig. 8.

By adding a demodulator diode and a patch antenna a high-performance Doppler sensor for speed over ground measurements has been built. The new Doppler sensor has a good signal to noise ratio and is already proven to work reliably in car tests [12].

CONCLUSION

The use of higher-order modes of conventional dielectric resonators together with very low-cost packaged HEMTs has led to a new type of DRO with excellent performance. The practical test in a Doppler sensor configuration under rough environmental conditions has proved the high reliability of all components. Furthermore, the fundamental-frequency oscillation at 24 GHz avoids unwanted spurious output at 12 GHz, which is a problem when using harmonic-mode oscillators. This demonstrates the potential of microwave techniques to be utilized not only for sophisticated purposes, but also in future very low-cost sensors (e.g. automotive applications).

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