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Review Article

Microwave Oscillator for High Volume Data Communication: A Review

Surendra M. Rakshit[a] | Vandana Malode[b]

Abstract

Wireless and mobile communications, as well as the development of RF and microwave test and measuring equipment are the most commanding drivers of RF technology during the last few years. Oscillators belong to the key elements of such analog and digital systems.

Day by day demand for higher bandwidth and frequencies in wireless and wire line applications continues to leap. This is increasing the burden on the RF industry to provide smaller size, lower power consumption, marginal cost, higher performance, higher functionality and rapidly new designs of RF and microwave components. Oscillators are the significant components of many communications, navigation, surveillance or test and measurement system. They provide a critical clocking function for high speed digital systems, generate electromagnetic energy for radiation, enable frequency up and down conversion when used as local oscillators and also act as a reference source for system synchronization. The market forces are motivating designers and developers to improve the performance of microwave components up to millimeter waves. This article reviews the developments in the field of microwave oscillators.

Keywords: RF and microwave, electromagnetic, synchronization, millimeter

Author Affiliation

[a]*Dr. Babasaheb Ambedkar Marathwada University, Aurangabad, Maharashtra, India*
[b]*Jawaharlal Nehru Engineering College, Aurangabad, Dr. B. A. M. University Aurangabad, Maharashtra, India*

Correspondence

Surendra M. Rakshit, Dr. Babasaheb Ambedkar Marathwada University, Aurangabad, Maharashtra, India
Email: ss2751986@gmail.com

Vandana Malode, Jawaharlal Nehru Engineering College, Aurangabad, Dr. B. A. M. University Aurangabad, Maharashtra, India
Email: vandana_malode@yahoo.co.in

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1. History

Microwave oscillators initially created with vacuum tubes and basically governed this field for three decades beginning from 1940. Reflex klystrons were a typical method to create low or direct powers at X-or Ku-band directly into the 1970s. The oscillators comprising of a klystron and its power supply itself used to be the size of some little test equipment of today, consumed more than 20 W of DC power and utilized 800 V of power supply to give 10 mW at X-band. However, it gave a clean signal because of the inherent high Q. By the late 1970s transistor dielectric resonator oscillators could give clean 10 mW of power at X-band utilizing 5 V and 30 mA in around one cubic inch of volume. Particularly surface-mount hybrid oscillators and complete MMIC arrangements can give necessary performance occupying considerably less volume and at a bit of the cost. With the introduction of solid-state devices, new devices started playing a role in signal generation solutions before 1970. Gunn and IMPATT diode oscillators overwhelmed signal generation applications before the three-terminal devices assumed control in the mid-1970s. Gunn diodes produce microwave energy utilizing the negative resistance characteristics of bulk semiconductor devices requiring standard, low impedance, steady voltage control supplies. Gunn diodes offer low phase noise, low power oscillators from 4 GHz to greater than 100 GHz. Gunn oscillators are as yet utilized at mm wave frequencies and use GaAs or InP materials relying on the frequencies and power required. Output power greater than 20 dBm can be acquired at 40 GHz with efficiency in the range of 2 to 3 percent. Gunn diodes are still viably playing at mm-wave frequencies where phase noise performance is hard to accomplish otherwise. IMPATT diodes were another early type of solid-state device producing high power microwave energy with efficiencies of 10 to 20 percent and covering frequencies up to and beyond 100 GHz. IMPATT diode oscillators however, have around 10 dB higher phase noise and offer a narrower tuning band than Gunn diode oscillators. IMPATTs find their application in higher power at higher frequencies. Depending upon the frequency and power required, Si or GaAs IMPATT diodes are utilized. More than 1 W of energy can be acquired at 40 GHz. The utilization of both Gunn and IMPATT diodes in microwave oscillator applications has been on the decay since three-terminal devices made their introduction in microwave frequency ranges around 1975. From then bipolar transistors and field-effect transistors took over the microwave active circuits domain enabling numerous new applications. It is more interesting to note, that even though latest technologies made great development in microwave signal generation, still today two-terminal solid-state devices are being used more effectively because of the performance edge, these devices have in specific areas. Transistor oscillators have made significant growth in the last quarter of a century. With low 1/f noise characteristics, Si BJT discrete device have produced incredible outcomes both in fixed tuned and tunable oscillators at frequencies beyond 20 GHz. GaAs, FET and HEMT devices are demonstrated to oscillate at frequencies above 100 GHz as principal oscillators. Commonly, in an oscillator, Si BJT devices offer around 10 dB better phase noise to GaAs FET devices. Flexibility and diversity of the three-terminal devices have produced a variety of technique to optimized distinctive parameters in different applications. Multi-frequency oscillators, push-push oscillator's, quenchable oscillators, optically controlled oscillators, Injection locked oscillators, self- oscillating mixer and regenerative frequency dividers are few of the example. Oscillators provide the pulse of all RF and microwave systems independent of their application. Most of the time performance of the oscillator decides key qualities of the subsystem. At the low end of the microwave frequency spectrum, mobile and developing wireless communications are the main motivation behind the advancement of microwave oscillators. On the high end of the spectrum, automotive radars, broadband radios and fast optical communication are fueling the need for volume. Special and exclusive oscillators are never lacking in demand to perform so called 'out of the ordinary' functions.

2. OSCILLATOR TOPOLOGIES AND TYPES

Microwave oscillators can be classified into a different types based on frequency bandwidth, kind of resonator used or sort of active device used. Resonators to a great extent decide frequency tuning range, stability and noise performance of the signal generator (oscillator), and are usually used to characterize diverse kinds of oscillators.

2.1. Fixed tuned oscillators

Fixed tuned oscillators are usually required for the most of the applications including as reference sources, fixed local oscillators and radars. These oscillators are usually described by low frequency drift and low phase noise. A high Q resonator is the key component for this kind of oscillator. An extensive variety of resonators with differing Q factors are now available everywhere. From low Q planar transmission line resonators to the highest Q sapphire loaded resonators, there are various distinctive kinds of resonators.

Metallic cavity resonators have for some time been utilized as high Q components for filters and low phase oscillators. Dielectric resonators are made of low loss, temperature stable, high permittivity and high Q ceramic material in a regular geometric form. The sapphire-loaded cavity resonator oscillator (SLCO) is another sort of low phase noise oscillator that uses sapphire, a low loss dielectric material. Ceramic coaxial resonator oscillators are fixed or narrowband tunable oscillators based on high Q ceramic resonators. Surface acoustic wave (SAW) oscillators using high Q lithium niobate devices empower the circuit to accomplish low phase jitter performance over a wide range of temperature. SAW oscillators have long filled the requirement for low phase noise oscillators at RF frequencies up to 2 GHz. Bulk acoustic wave resonator (BAW) oscillators are a current presentation in the field of fixed frequency oscillators. YIG-tuned oscillators (YTO) are utilized as a part of test and measurement and in addition in wideband military system requiring multi-octave bands of tuning. YTOs are oscillators of choice when wideband tuning, high tuning linearity and good phase noise are simultaneously required.

2.2. Frequency tunable oscillators

Wideband tunable oscillators are vital parts for ESM, ECM and test instrumentation, and in addition numerous communication system. These are described by the tuning bandwidth and linearity, phase noise, settling time and post tuning drift. The requirements for the particular characteristics rely on the application. Compromises are called for in the view that these parameters can't be achieved using single technology or method. In order to get oscillation over a wideband the active device needs to have negative resistance over the band and the frequency tuning component needs to tune over the band. Design technique are then used to fulfill oscillation conditions over the band while optimizing more than one parameters. Phase noise being a function of the carrier frequency and tuning bandwidth.

2.3. State-of-the-art for oscillators

In state of the art a microwave oscillator has been studied and comparative is done. In first paper author has used 0.18µm CMOS technology and has designed microwave VCO operating between 1.9-3GHz with phase noise of -122@1MHz. And the rest of comparison is shown in Table below.

2.4. Effect of increasing clock speeds in the digital world

Speed with which digital signals are processed have been expanding at very fast step requiring the clock to move up in frequency to the microwave region. Optical communication system are currently working at 2.5 Gb/s, 10 Gb/s and 40 Gb/s requiring clock signals at 10, 20 and 40 GHz. 10 Gb Ethernet is already in used and use of 100 Gb Ethernet is probably going to begin this year. Various digital communication system and storage systems are working at speeds higher than 1 Gb/s. CPUs are working at microwave frequencies. Microwave broadband radios are already giving data bandwidth more than 1 Gb/s. Microwave part manufacturers need to get comfortable with new requirement and terminology in the digital world. Digital engineers are more inclined towards RF/microwave techniques. Oscillators play out a key "clock" function in the computerized world in both wired and also remote applications. In the Digital world the performance of the signal source is measured as jitter rather than phase noise. As a general rule these clock signals are microwave oscillators requiring certain features and characteristics. Oscillators like ring oscillators, I/Q oscillators, differential cross coupled oscillators and multivibrators are currently being utilized at microwave frequencies in various applications. A low jitter clock source is a key prerequisite of low BER digital communication systems. However, jitter and phase noise are related. Clock jitter is characterized as the variation in timing of periodic waveform with respect to a jitter free reference. At slow speed oscilloscopes or communication analyzers can simply quantify the jitter from the wave shape. However at 10 Gb/s or more it is substantially harder to quantify the clock jitter using traditional techniques. A phase noise measurement capable of measuring a very low level instability is a practical tool to understand the source phase jitter at high frequencies. Jitter is computed from the estimation of integrated phase noise over a fixed offset bandwidth (50 kHz to 80 MHz for OC-192, for example) and is represented in various units, including radians, degrees, time (seconds) and UI (unit interval). Different types of jitter including period jitter, cycle-to-cycle jitter and time interval error are in some ways related to phase noise or frequency stability of the microwave oscillator. Oscillators required to clock analog to digital converters (ADC)/digitizers working at multi-gigahertz frequencies require a low noise to improve signal to noise ratio performance of the converter. Noise produced by a clock source can add jitter to an ADC, which causes degradation of the SNR of the ADC.

3. DEVELOPMENT IN TERA BAND SIGNAL GENERATION

Kyoya Takano, Kosuke Katayama reported a 300-GHz CMOS transmitter with 21Gb/s Maximum Data Rate Per-Channel. It employed six channel cubic mixer. It contain a set of local oscillator used for up conversion up to 300GHz.

F. Lenk, M Schott has investigated optimizing MMIC reflection type oscillator. It supports frequency generation upto 35 GHz and give a phase noise upto -85dBc/Hz at 100 Khz offset frequency. The design oscillator uses two finger 3×300 μm^2 InGaP/GaAs HBT. A Varactor based frequency tunning is achieved upto 2.4 GHz (6.8%).

Robbert Wanner, Gerhard R. Olbrich has developed 70GHz SiGe based low phase noise push-push oscillator. A semiconductor device used in this work provides a maximum oscillation upto 275 GHz. Here the oscillator frequency is tunned from 63 GHz to 72 GHz which deliver the output power between -1.8dBm & +1.6 dBm with a phase noise less than -103dBc/Hz at 1 MHz offset frequency.

Robbert Wanner and his colleague suggested that push oscillator is more suitable for design of low phase noise oscillator. In comparison with frequency doubler for frequency enhancement, push oscillator is generally less space consuming and offer less phase noise. Additionally this topology is highly resistant to load pulling effect because of sub oscillator virtual ground. Here the frequency tuning has been achieved by varying bias voltage between -1.5 V to -4.5 V so that the oscillation frequency can changes from 72.23GHz to 63.66 GHz respectively. The maximum output power deliver by this oscillator was measured as 1.6 dBm.

Ref.	**Technology Used**	**Central Frequency-Fc (GHz)**	**Power Consumption (mw)**	**Output Power(mw)**	**phase noise (dBc/Hz)**	**Tuning range (Relative BW) (%)**	**Figure of Merit (FOM) (dBc/Hz)**
[1]	0.18µm CMOS	3.04	5.4		-122.9@1MHz	48	-185.11
[2]	0.15µm GaAs pseudomorphic high- electron mobility transistor (pHEMT)	2.5		21dBm	-106.3@1MHz	23.5-24.5 GHz	-187.2
[3]	Stubs Loaded Nested Split-Ring Resonator	1.98		9.5 dBm	− 127.22@100 kHz and −145.43@1MHz	18%	− 198.4
[4]	SiGe HBT & Dual Mode Circular Cavity (DMCC) SIW bandpass filter (BPF)	10.17	13.6	-1.35dBm	− 135.4@1MHz		-204.4
[5]	90-nm CMOS	5.86 GHz	40.8	-15dBm	-11.22@1MHz	30.2% (23.6 to 32 GHz)	
[6]	two-pole coupled-resonator and three-pole combline filters	2.05 GHz	20		-148.3@1MHz	54.8% (1.3 to 2.2813 GHz)	-188.32
[7]	Coupled line Resonator	1.92 GHz		5.23 dBm	-112@100KHz		
[8]	SiBJT bandpass filter (BPF) using a composite right/left-handed transmission line (CRLH TL).	2.05 GHz	6.1 mW	3.4 dBm	− 150.4 @100KHz		− 207.2 @1MHz
[9]	3-pole Butterworth filter as a resonator	2.4 GHz	24 mW	3.38dBm	-147 @1MHz	0.80%	-203.18

In future submillimeter and millimeter wave application like a high resolution RADAR, large bandwidth communication system and many more are the key component of compact, reliable low noise source. Here Robbert Wanner and his team developed such a low noise SiGe push-push oscillator for above mentioned application. The designed oscillator generates the oscillation between 47 GHz to 1901 GHz. The passive circuitry is designed using integrated transmission line component, integrated spiral inductor, MIM capacitor and Tan resistor. The above frequency of oscillation is achieved by varying capacitance of base collector junction as a tuning Varactor. In this frequency range the output power 3.5±0.4 dBm is reported.

Jonghoon Choi and Amir Mortazawi studied reduction in 1/f noise by means of push-push and triple push oscillator. Low frequency 1/f noise plays a dominant role in determining close to carrier frequency performance. It is well known that 1/f noise is up converted to carrier frequency. Furthermore mathematical analysis suggested that by taking odd harmonic frequency at the output one can reduce the effect of 1/f noise. For the oscillator design GaAs MESFET device is used. In the asymmetrical triple push-push oscillator without even harmonic the oscillation frequency and the output power reported as 5.85 GHz & 2 dBm.

Omeed Momeni & Eshan Afshari implemented Terahertz and MM wave oscillator for delivering high power and high frequency. The design oscillator are intended to operate 121 GHz and 104 GHz with output power of -3.5 dBm and -2.7 dBm. Also author has developed a triple push-push oscillator, oscillating at 256 GHz and 482 Ghz respectively. For many application high frequency signal generation required specifically Image and biomolecular spectroscopy is the first and main application of terahertz band. According to authors observation output power is higher in CMOS and SiGe in comparable with oscillator using InP HEMT and InP HBT.

Atshushi Kanno and team members has developed 100GHz and 300 GHz. RoF transmission using optical frequency comb source. Direct and seamless conversion of optical and radio signal with high capacity transmission link has a great demand in future network access because of increase in network traffic. For high capacity radio communication possible frequency band is only MMW band. However in this band it has large atmospheric attenuation and because of this communication distance is limited to 20m only. On the other hand frequency band like 100 GHz and 300 GHz has relatively small atmospheric attenuation up to 0.4 DB/Km for 100 GHz and 3 DB/Km for 300 GHz, so that communication distance can be extended to 100m or more.

4. Conclusion

It is a time of unprecedented change, where traffic on telecommunication networks is growing exponentially, and many new services and applications are continuously emerging. Resonators are the key performance component of many RF/Microwave component such as Oscillator and Filters. The next generation of wireless communication systems needs such high speed oscillator. In this articles one introduced the history of oscillator including its types. Also development in the microwave band and tera band is explained.

Conflict of Interests

The authors declare that there is no conflict of interest related to the publication of this article.

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