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Local Oscillators in Electronic Warfare Applications

Linh V. T. Nguyen

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ABSTRACT

Local oscillators (LOs) are required whenever heterodyning is utilised in receiver architectures to convert high-frequency signals to an intermediate-frequency (IF) spectrum for ease of processing. Utilisation of the heterodyning technique includes applications ranging from Electronic Warfare (EW) to radio astronomy. While EW involves the interception and exploitation of signals across the complete electromagnetic (EM) spectrum, the range of frequencies of interest in this report is from near DC and up to millimetre wave (~110 GHz). Radio astronomy shares similarities with EW in the detection of wideband EM signals ranging from radio and up to sub-millimetric frequencies.

This technical report focuses on the requirements of LOs in EW receiver systems. In particular, LO technologies including frequency synthesisers, quartz, yttrium iron garnet (YIG) and Gunn-effect electronics will be discussed in order to derive a suitable benchmark, in terms of tunability, amplitude accuracy and stability, frequency accuracy and stability, and phase noise level, for the development of photonic LOs.

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Executive Summary

Photonic technology is characterised by low attenuation, wide bandwidth and immunity to electrical interference, which are ideal for the manipulation of radio frequency, microwave and millimetre-wave signals. In particular, photonics has been proposed as an enabling technology for wideband receiver architectures for Electronic Warfare (EW) applications. In addition, this new technology has the potential to simplify receiver architectures, which in turn has cost-reduction benefits, while maintaining receiver performance.

One area where photonics can provide an advantage is for distribution of the local oscillator (LO) frequency in complex EW systems utilising heterodyning reception. Achieving this using an optical signal distributed over a fibre-optic network to multiple mixers in a system gives advantages in terms of reduced complexity, weight and cost over the use of electrical components. Further advantage is gained if the LO signal can be generated directly in the optical domain, as electrical modulation of the optical carrier is not required, and the potential to reach millimetric frequencies may be realised. However, the development of photonic LOs is still in its infancy. In order to be accepted as an alternative LO solution in heterodyning receiver design, photonic LOs should at least have the same performance as existing commercial-off-the-shelf (COTS) technologies, e.g. frequency synthesisers, quartz, yttrium iron garnet (YIG) and Gunn-effect electronics.

The development of photonic LOs needs a performance benchmark to guide its development suitable for EW applications, which specifies LO requirements in EW receiver systems in terms of tunability, amplitude accuracy and stability, frequency accuracy and stability, and phase noise level. Trade-offs between these various parameters are necessary for any given EW applications. However, the performance benchmark cannot be so easily identified and extracted, because operational parameters of EW systems on state-of-the-art airborne, maritime and land-based platforms remain classified. In order to derive such a benchmark, common commercial-off-the-shelf (COTS) LO technologies such as frequency synthesisers, quartz, YIG-tuned devices and Gunn-effect electronics have been reviewed to extract their best performance parameters.

Author

Linh V T Nguyen
Electronic Warfare & Radar Division

Linh Nguyen received the BSc in 1992 and BE (EEE) in 1993 from the University of Adelaide, and PhD in 1997 from the Photonics Research Laboratory, Australian Photonics Cooperative Research Centre, Department of Electrical & Electronic Engineering, University of Melbourne.

He has held positions at the Photonics Research Laboratory, Vicom Australia Pty. Limited and Acterna Asia-Pacific Pty. Limited. He has also completed a Master of Marketing at the Melbourne Business School. He currently holds a Research Scientist position in the Electronic Warfare & Radar Division, DSTO Edinburgh, where his research interests are in the field of microwave photonic signal processing and its applications to Electronic Warfare. He is the Task Manager for Photonic Systems Technology in the Electronic Warfare & Radar Division.

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1. Introduction

Electronic Warfare (EW) is an important capability in deciding the outcome of military campaigns. EW capability can advance desired objectives or, conversely, impede undesired ones [1-7]. It provides measures to self-protect and counter against threats through the interception and exploitation of the electromagnetic (EM) spectrum.

1.1 Wideband Enabling Technology

A key requirement for EW systems is the determination of the presence of threat signals and suitable countermeasures over a very wide bandwidth. The reason for the very wide bandwidth requirement is that electromagnetic (EM) threats are no longer limited to radio and microwave frequencies. Potential hostile threats now exist at millimetric frequencies with the emergence of a new class of radar and weapon systems based on monolithic microwave integrated circuit (MMIC) technology [7]. Commonly exploited millimetric frequencies are in the 35 GHz (Ka-band) and 94 GHz (W-band) windows, which are advantageous due to the low atmospheric attenuation depicted in Figure 1.

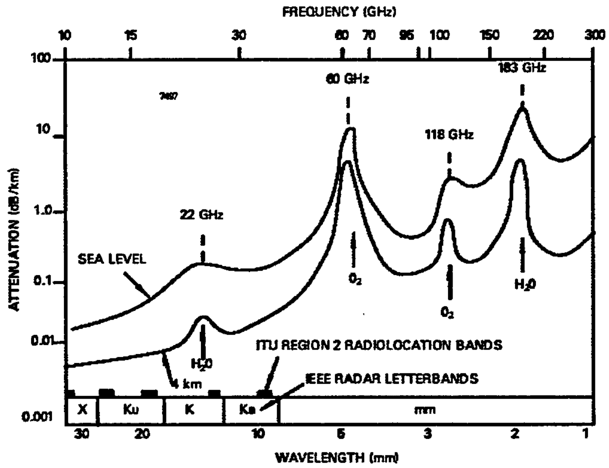


Figure 1: Typical atmospheric attenuation at microwave and millimetric frequencies.

There are known disadvantages with using millimetric frequencies including performance degradation due to bad weather and high cost. However, these drawbacks are often out-weighed by several advantages [7]:

1. Reduction in antenna physical size for a given gain,
2. Increase in antenna gain for a given physical aperture size,
3. Potential for better angular resolution,
4. Potential for improved targeting and tracking accuracy, and
5. Reduction in EM environment clutter and interference.

It is paramount to realise that potential hostile threats are now wideband covering from low radio and up to millimetric frequencies on the EM spectrum. There is a definite need for an enabling technology that is capable of processing such wideband EM threats.

Photonics has been proposed as an enabling technology for wideband receiver architectures for Electronic Warfare (EW) applications. Photonic technology is characterised by low attenuation, wide bandwidth and immunity to electrical interference, which is ideal for the manipulation of radio frequency, microwave and millimetre-wave signals. It holds a unique capacity for EW systems to be optically re-configured to fulfil system functionalities over very wide bandwidths [8-11], including both Electronic Support (ES) and Electronic Attack (EA). In addition, this new technology has the potential to simplify receiver architectures, which in turn has cost-reduction benefits, while maintaining receiver performance. A more flexible and affordable solution will have a significant impact on the ability to provide the best possible self-protection and force-level protection measures.

1.2 Frequency Conversion Requirements

Photonics has been successfully demonstrated in applications of optoelectronic mixers and ES superheterodyne receivers [8,12]. Like its electronic counterpart, the photonic heterodyne receiver requires a local oscillator (LO) to shift the signals of interest to an intermediate frequency (IF) spectrum for ease of processing. The exploitation of photonics in heterodyne receiver architecture dictates a need for photonic LO signal generation to take advantage of unique properties offered by fibre-optic components and systems [13,14].

The generation and distribution of LO signals in complex heterodyne receiver architectures involving a number of mixers can be difficult at microwave and millimetric frequencies [10]. Photonics was proposed, over a decade ago, as an alternative technology to generate and distribute LO signals for EW applications [10,15]. However, the primary driving force behind the development of photonic LO in recent years has been radio-astronomy applications [14,16-18], in which heterodyne receivers are used. There are many LO requirements in radio astronomy [18], which may be applicable in EW systems:

1. Constant power required from 80 GHz to 1 THz.
2. Narrow linewidth requiring phase locking.
3. Low amplitude and phase noise.
4. Tunability.

In comparison to radio astronomy, the main performance measure for EW receivers is the low noise figure in the IF spectrum [19]. This leads to the following LO requirements for EW applications [19]:

1. Low amplitude noise. High LO amplitude noise can only be tolerated if the mixers used in the receiver design have excellent LO noise suppression, i.e. 35 dB or better.
2. Whenever frequency identification is needed, LO frequency accuracy is required.
3. Low LO phase noise and frequency stability is required when coherent detection scheme is utilised.
4. Tunability adds scanning capability to the receiver design.

The LO requirements for EW receivers are very similar to those of radio astronomy. The above LO requirements highlight the need for practical design trade-offs between various LO parameters in EW receiver systems.

1.3 Accuracy and Stability

The difference between accuracy and stability must be clarified to avoid confusion. According to the National Institute of Standards and Technology (NIST) [20], accuracy is defined as the degree of conformity of a measured or calculated value to the definition. Consequently, accuracy is related to the offset from an ideal value. Whereas stability is determined by how well a parameter can be produced to the same value over a given interval of time. Stability does not indicate whether the value of that parameter is right or wrong, but only whether it stays the same.

1.4 Phase Noise

Phase noise of a LO signal, f_{lo}, can be defined generally as the ratio of the noise power density in one sideband at an offset frequency, f_{off}, for a 1 Hz bandwidth, to the LO signal power [20]. The unit for phase noise is dBc/Hz. The concept of phase noise to represent a noisy LO signal is depicted in Figure 2.

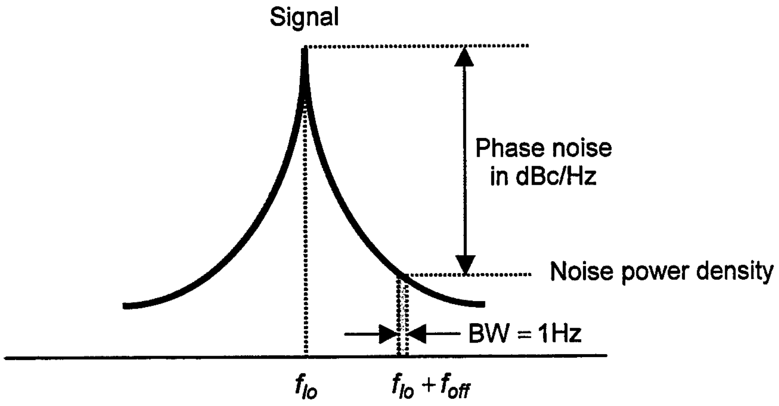


Figure 2: Spectrum of a noisy LO signal illustrating the concept of phase noise.

1.5 Research Objective

In this report, the emphasis is placed on the LO specifications in heterodyne receivers operating from near DC and up to millimetric frequencies in EW systems. In particular, the research objective is to derive a suitable performance benchmark, in terms of tunability, amplitude accuracy and stability, frequency accuracy and stability, and phase noise level, to assess the quality of photonic LOs under development for EW receiver applications. Two examples of such LOs under development are:

1. "Tunable microwave source based on Nd:YAG laser", DSTO Collaborative Research Project with Associate Professor Judith Dawnes, Macquarie University.
2. "SIDEARM CTD Module 4 - Photonic Oscillator", Collaborative Research Agreement between Australian Photonics Pty. Limited and the Commonwealth of Australia.

However, such a performance benchmark is not so easily identified and extracted, because operational parameters and system specifications of EW systems on airborne, maritime and land-based platforms remain classified. However, photonic LOs should at least have the same performance as existing commercial-off-the-shelf (COTS) technologies, which are frequency synthesisers, quartz, yttrium iron garnet (YIG) and Gunn-effect electronics. These COTS LO technologies will be reviewed to extract their best performance parameters, which can then be utilised as a suitable benchmark to compared photonic LOs.

1.6 Report Outline

The report is structured in the following manner:

- *Utilisation of LO in Heterodyne Receiver Design* section outlines important issues and how a heterodyne receiver works.
- *Current LO Technologies* section summarises LO technologies from low-frequency quartz oscillator to millimetre-wave oscillators based on Gunn-effect electronics.
- *Commercial LO Performance* section summarises typical performance of commercially available LO technologies discussed.
- *LO Specifications in Electronic Warfare Receivers* section details the benchmark for the development of photonic LO, in terms of tunability, amplitude accuracy and stability, frequency accuracy and stability, and phase noise level.
- *Photonic LO Techniques* section reviews various photonic techniques to generate LO signals ranging from radio and up to millimetric frequencies.
- *Conclusions* summarise the results of this report.
- *Recommendations* detail research directions into the development of photonic oscillators for EW applications.

2. Utilisation of LO in Heterodyne Receiver Design

A heterodyne receiver, often referred to as a superheterodyne or superhet receiver [3], converts the signals of interest at high frequencies to a lower intermediate frequency (IF) spectrum for ease of processing. The utilisation of IF amplifiers improves the sensitivity and selectivity of the receiver [3]. High-frequency amplifiers may not be available or cost effective.

2.1 Principle of Operation of a Heterodyne Receiver

A basic heterodyne receiver is as shown in Figure 3. It contains a mixer, a local oscillator (LO) and the IF detection circuitry.

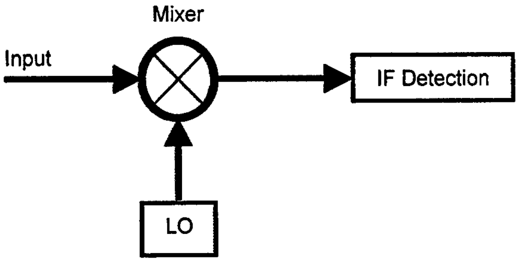


Figure 3: A basic heterodyne receiver.

The principle of operation of the receiver in Figure 3 can be explained through the equation describing the output current of the mixer. The mixer can be described using the following nonlinear relation [3]:

$$I = \sum_{i=0}^{N} a_i V^i \tag{1}$$

where I is the current through the mixer, V is the voltage applied across the mixer and a_i are constants associated with the mixer. Equation 1 can be considered as a power series approximation of the exponential function of the diode equation [3]. The voltage applied across the mixer is the sum of the input and LO signals [3]:

$$V = (V_{lo} + v_{lo}(t))\sin(2\pi f_{lo} t + \varphi_{lo}(t)) + (V_S + v_S(t))\sin(2\pi f_S t + \varphi_S(t)) \tag{2}$$

where V_{lo}, $v_{lo}(t)$, f_{lo} and $\varphi_{lo}(t)$ are the amplitude, amplitude fluctuation function, frequency and phase fluctuation function of the local oscillator, respectively. Similarly, V_S, $v_S(t)$, f_s and $\varphi_S(t)$ parameters represent the input signal.

Substituting Equation 2 into 1 results in:

$$\begin{aligned} I = a_0 \; + \; & a_1\{(V_{lo}+v_{lo}(t))\sin(2\pi f_{lo}t+\varphi_{lo}(t))+(V_s+v_s(t))\sin(2\pi f_s t+\varphi_s(t))\} \; + \\ & a_2\{(V_{lo}+v_{lo}(t))\sin(2\pi f_{lo}t+\varphi_{lo}(t))+(V_s+v_s(t))\sin(2\pi f_s t+\varphi_s(t))\}^2 \; + \cdots \end{aligned} \qquad (3)$$

The first term is a DC component, whereas the second term represents the original input and LO signals. The third term would give the desired frequency conversion. The quadratic expression without a_2 is:

$$\begin{aligned} & \{(V_{lo}+v_{lo}(t))\sin(2\pi f_{lo}t+\varphi_{lo}(t))+(V_s+v_s(t))\sin(2\pi f_s t+\varphi_s(t))\}^2 \; = \\ & \quad (V_{lo}+v_{lo}(t))^2\sin^2(2\pi f_{lo}t+\varphi_{lo}(t)) \; + \\ & \quad (V_s+v_s(t))^2\sin^2(2\pi f_s t+\varphi_s(t)) \; + \\ & \quad (V_{lo}+v_{lo}(t))(V_s+v_s(t))\begin{pmatrix} \cos(2\pi(f_{lo}-f_s)t+\varphi_{lo}(t)-\varphi_s(t)) \; - \\ \cos(2\pi(f_{lo}+f_s)t+\varphi_{lo}(t)+\varphi_s(t)) \end{pmatrix} \end{aligned} \qquad (4)$$

Therefore, the IF component resulted at the output of the mixer when $f_{lo} \geq f_s$ is:

$$a_2(V_{lo}+v_{lo}(t))(V_s+v_s(t))\cos(2\pi(f_{lo}-f_s)t+\varphi_{lo}(t)-\varphi_s(t)) \qquad (5)$$

The IF frequency is given as $f_{if}=f_{lo}-f_s$. Similarly, the IF component can be represented by $f_{if}=f_s-f_{lo}$ when $f_s > f_{lo}$. The IF component in Equation 5 must be filtered out from other high-frequency components produced by the mixer, and then amplified to improve detection sensitivity and selectivity.

2.2 Qualitative Analysis of LO Requirements

Equation 5 can be qualitatively analysed to identify LO requirements in the heterodyne receiver arrangement.

2.2.1 Amplitude

The IF amplitude in Equation 5 can be expanded fully to give:

$$a_2\{V_{lo}V_s+V_{lo}v_s(t)+V_s v_{lo}(t)+v_s(t)v_{lo}(t)\} \qquad (6)$$

The first term of the IF amplitude is constant, while the others result from amplitude fluctuations from both the input and LO signals. There is little that can be done about the amplitude fluctuation of the input signal. However, if the amplitude fluctuation of the LO signal is significant suppressed, then the IF amplitude converges to:

$$a_2\{V_{lo}V_s+V_{lo}v_s(t)\} \qquad (7)$$

Equation 7 is true if the LO signal has low amplitude noise. In other words, the LO has high amplitude stability, which is very important. Equation 7 also holds if the mixer has high LO noise suppression [19]. Furthermore, Equation 7 states that the IF amplitude is proportional to the LO amplitude, but detection sensitivity and selectivity can be improved by using IF amplification to compensate for low LO power.

For simplicity, a single-diode mixer model in Equation 1 was used to derive Equation 5 on which this qualitative analysis is given. The most common mixer in Electronic Warfare (EW) equipment is the double balanced mixer, which utilises four diodes in a ring configuration [3]. This double balanced mixer provides very good suppression of LO amplitude noise and high dynamic range.

2.2.2 Frequency

If the LO frequency were tunable over a limited range, it would imply that the heterodyne receiver can be utilised to detect input signals over the same bandwidth with the same IF detection circuitry. LO frequency tunability enhances the flexibility of the receiver.

Once the resultant IF frequency is measured with a calibrated instrument, it can be used to determine the input signal frequency if the LO frequency is known. This requires the LO frequency to be accurate over time. Both LO frequency accuracy and stability are essential in such applications.

2.2.3 Phase Noise

LO phase noise is related to its linewidth, not to be confused with LO frequency stability. In can be seen from Equation 5 that the phase fluctuation of the IF component depends on the phase fluctuations of both the input and LO signals, i.e. $\varphi_{if}(t) = \varphi_{lo}(t) - \varphi_{s}(t)$.

The phase noise level is not so critical if the signals in the frequency range of interest are discrete and spaced far apart from each other. However, high LO phase noise would worsen the frequency selectivity of the receiver when the signals are close together. If the LO has low phase noise, then the IF phase fluctuation converges to that of the input signal.

2.3 Photonic Heterodyne Receiver

Photonic technology has been proposed as an enabling technology to implement wide-bandwidth EW receivers [8-11]. Figure 4 illustrates a basic architecture of a heterodyne receiver based on photonic technology including the mixer function [12], which is equivalent to the electronic version shown in Figure 3.

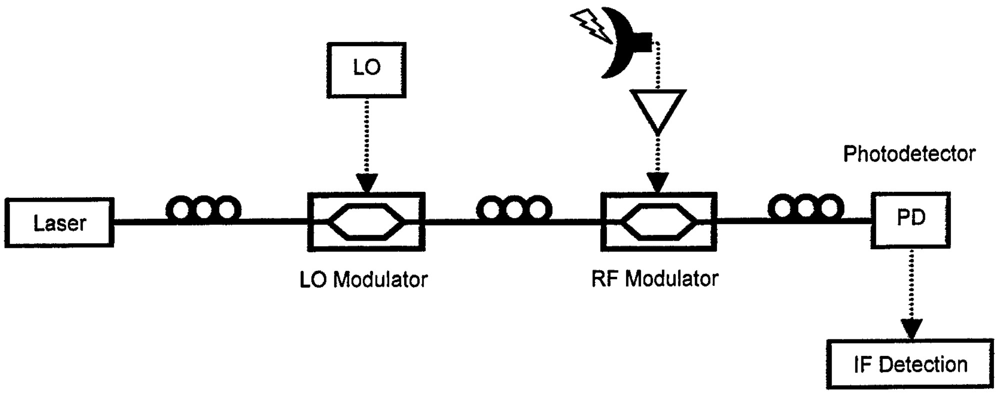


Figure 4: Heterodyne receiver design based on photonic technology [12].

In Figure 4, the photonic LO signal is generated by directly modulating an electrical LO onto an optical carrier with the first modulator. Photonic mixing occurs at the second modulator. The electrical-optical conversion efficiency of the modulators requires careful consideration to ensure high sensitivity and selectivity for the complete receiver. The advantages of the photonic mixer shown in Figure 4 include [12]:

- Wide bandwidth of operation,
- Minimal third-order intermodulation product, and
- Infinite isolation between the LO and RF ports.

2.4 Summary

Qualitative analysis highlights the following LO requirements in heterodyne receiver architecture:

1. Amplitude stability is important.
2. Tunability is desirable.
3. Frequency accuracy and stability are essential.
4. Low phase noise is desirable.

These general qualitative requirements are similar to those stated by Bernues *et al.* [19] for millimetre-wave receivers. Having all four above properties in a single LO design would be ideal, but trade-offs between various parameters are necessary. Any trade-off would be application specific.

3. Current LO Technologies

This section provides an overview of a number of current electronic local oscillator (LO) technologies from near DC up to millimetric frequencies. LO technologies to be reviewed include quartz, yttrium iron garnet (YIG) and Gunn-effect electronics. It is not meant to provide in-depth discussions on how to design these oscillators. Readers may refer to the references listed at the end of the report and others for more information.

3.1 Quartz Oscillator Technology

Quartz is basically silicon dioxide (SiO_2), which remains crystalline even at high temperature [21]. In 1880, Pierre and Jacques Curie discovered that quartz crystals could be made to vibrate by applying an electric field to them [22]. Oscillation is completely sustained by amplifying the voltage signal from the resonator and then feeding it back [20]. The rate of expansion and contraction of the quartz crystal is the oscillation frequency. Quartz can be made to vibrate at any frequency, up to tens of MHz, by cutting it in different ways [20,22].

Quartz oscillator technology plays a critical role in serving applications ranging from satellite communication systems to digital telephone base stations and networks [23]. Quartz oscillators can be designed to exhibit stringent performance requirements including superior thermal stability, low phase noise, low power consumption, small size, low cost and high reliability based on double oven control design, i.e. OCXO [23]. Two major drawbacks of quartz oscillators are aging and slow warm-up.

3.2 Atomic References

Atomic oscillators, which are often referred to as atomic clocks, are known for their accuracy and stability. The two most common types are based on Rubidium (Rb) and Cesium (Cs), with the latter having better quality and being more expensive.

3.2.1 Rubidium Oscillator Design

Figure 5 shows the arrangement of the Rb oscillator [20]. It operates at the resonance frequency of Rb-87 atoms, i.e. 6,834,682,608 Hz. In the Rb oscillator design shown in Figure 5, Rb-85 isotopes are used to filter out one suitable optical frequency to excite the Rb-87 atoms. This is possible because both Rb-85 and Rb-87 isotopes have a common resonance transition. The excitation of Rb-87 atoms can be explained using the energy-level diagram shown in Figure 6. The filtered rubidium lamp excites the Rb-87 atoms to the metastable state, ${}^2P_{3/2}$, from which they decay back to the ground state hyperfine levels, $F=1,2$, with equal probability. With continuous optical pumping, all Rb-87 atoms are found in the $F=2$ level and no further absorption occurs. If a microwave field is now applied, corresponding to the $F=2 \rightarrow F=1$

transition, then $F = 1$ level is repopulated. This microwave-induced energy-state transition increases the absorption of the optical pump by the Rb-87 buffer gas atoms.

The amount of optical absorption is then measured and used to tune a quartz oscillator and frequency synthesiser to a frequency that maximizes the amount of light absorption. In this arrangement, the quartz oscillation is disciplined by the resonance frequency accuracy and stability of Rb-87 atoms. Being "disciplined" is a standard terminology associated with frequency synthesisers to describe it being locked to a reference signal with a feedback loop configuration. The reliability of Rb oscillators is determined by the limited life of the Rb lamps, while their size, cost and power consumption characteristics are poor.

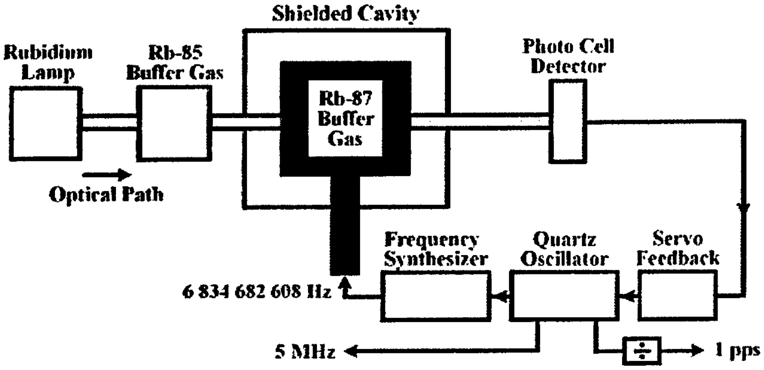


Figure 5: Rubidium oscillator design [20].

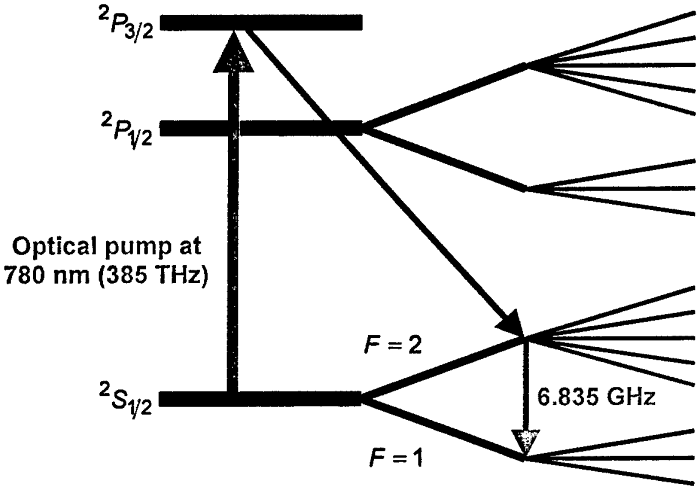


Figure 6: Energy levels and transitions in Rb-87 during operation of oscillator.

3.2.2 Cesium Oscillator Design

Cs oscillators are also known as primary frequency standards since the International System (SI) second is defined as the duration of 9,192,631,770 periods of the resonance frequency of Cs-133 atoms [20]. Figure 7 shows a typical arrangement of a commercial Cs oscillator. In this arrangement, Cs-133 atoms are heated to a gaseous state and selected for a particular magnetic energy state to pass through a gate into a microwave cavity. They are then exposed to microwaves derived from a quartz oscillator. If the microwave frequency matches the resonance frequency of Cs-133 atoms, then the Cs-133 atoms change their magnetic energy state. Those Cs-133 atoms that changed their magnetic energy state are further selected and directed to a detector. The output of the detector is used to tune the quartz oscillator to obtain the greatest number of Cs-133 atoms reaching the detector. The quartz oscillator is disciplined by the resonance frequency of the Cs-133 atoms.

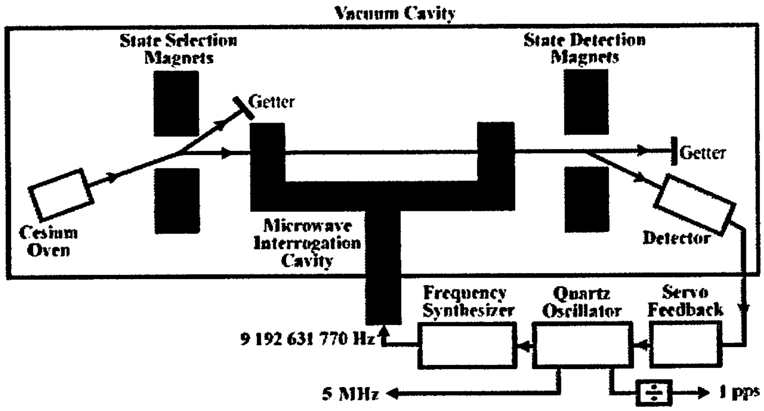


Figure 7: Cesium oscillator design [20].

While atomic oscillators are highly accurate and stable, both Rubidium and Cesium oscillators are complex, bulky and expensive making them only suitable for synchronisation of telecommunications networks [24] and timekeeping, e.g. the Global Positioning System (GPS) for navigation [25].

3.3 Frequency Synthesis

From the design of both Rb and Cs oscillators shown in Figures 5 and 7, quartz oscillators are locked to the atomic resonance frequencies of Rb and Cs, respectively. In order to generate suitable microwaves to input into the interrogation cavity, frequency synthesisers were needed to generate frequencies of 6.835 and 9.193 GHz for the Rb and Cs oscillators, respectively.

Frequency synthesis is an extremely useful method to produce high frequency LO signals from a low-frequency reference oscillator, e.g. double oven controlled crystal oscillator (OCXO). A generic frequency synthesiser is illustrated in Figure 8 [26-33]. It consists of a reference oscillator, a phase-locked loop (PLL) and a frequency multiplier. The PLL is a feedback circuit consisting of a phase comparator, amplifier and low-pass filter acting as an integrator, a voltage-controlled oscillator (VCO) and a frequency divider on the feedback path.

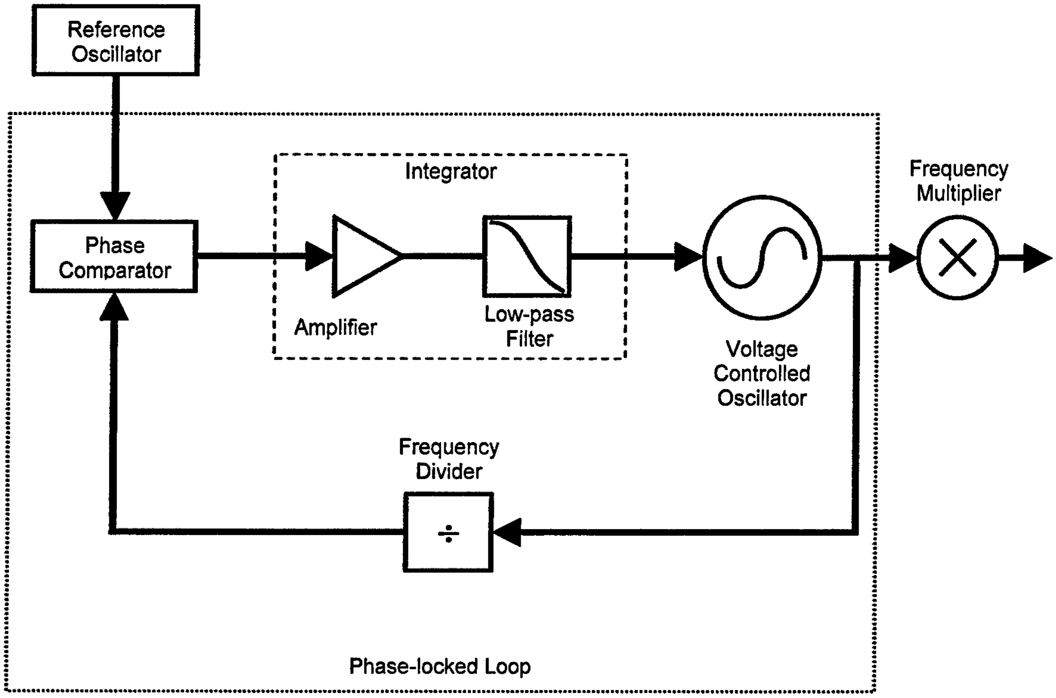


Figure 8: A generic frequency synthesiser.

3.3.1 Phase-Locked Loops

The VCO is a frequency source whose output frequency is controlled by the input applied voltage. However, its frequency accuracy and stability, and phase noise are vulnerable to the fluctuation of the input applied voltage. This problem is solved through phase locking in a loop configuration known as PLL.

The emphasis on the PLL here is its utilisation in frequency synthesis rather than signal detection in a noisy environment. The majority of inexpensive frequency synthesisers use PLLs [32]. The reference signal in PLL design is provided by high-quality quartz oscillators, which exhibit the necessary frequency accuracy and stability, and low phase noise.

The function of the PLL, as illustrated in the generic frequency synthesiser in Figure 8, is to track and correct small differences in phase between the reference and feedback signals [32]. The feedback signal has to be frequency divided to the same frequency as the reference. The phase comparator measures the phase difference between its two inputs. The resultant output of the phase comparator is amplified and filtered through a low-pass filter before feeding into the VCO to adjust the output frequency accordingly. The PLL is locked when the phase difference detected by the phase comparator is zero. This is when the frequency accuracy and stability is locked to that of the reference source.

Interested readers can refer to Reference 32 for more details on the design of PLLs. Digital PLL technology is also discussed in Reference 32.

3.3.2 Frequency Multipliers

To illustrate the need for the frequency multipliers at the output of the PLL, the following frequency synthesis examples are used:

1. Fixed LO signal at 40 GHz.
2. Tunable LO signal from 30-40 GHz.

VCO technologies offer a range of output frequencies and tunability [33]. Trade-offs between cost and performance must be considered. High-frequency VCOs are often not commercially available [33]. In the first example, it is not possible to synthesise 40 GHz directly from a PLL using a low-frequency VCO [33]. If the VCO operates at 10 GHz, then a frequency multiplication factor of 4 is required to achieve 40 GHz. In the second example, a tuning range of 10 GHz is required, which is beyond the capabilities of most VCOs [33]. However, a PLL with a suitable VCO can achieve a smaller tuning range and at a lower frequency, e.g. 3.75-5 GHz. Frequency tuning is possible by varying the loop parameters while keeping the reference signal fixed. Then a frequency multiplication factor of 8 is required to achieve the desired 30-40 GHz LO signal.

One major drawback when using frequency multipliers is the enhancement of phase noise. In applications where low phase noise is required, it would be better to frequency divide from high-frequency LOs [33].

3.4 Yttrium Iron Garget Tuned Oscillator Technology

Yttrium iron garnet (YIG) is a ferrimagnetic material that possesses unique properties. YIG is not a naturally occurring material, but synthesised [34]. Its chemical composition varies from $Y_3Fe_5O_{12}$ [34], $5Fe_2O_33YO_3$ [35], $Y_2Fe_2(FeO_4)_3$ [36] and $Y_2Fe_2(FeO_3)_3$ [37].

3.4.1 Magnetic Resonance

YIG has been utilised in the design of both filters and LOs, with the former being beyond the scope of this report. YIG can be made to resonate with high quality (Q) factor from radio, microwave and up to millimetric frequencies by varying the biasing DC magnetic field [34-46]. The resonance of YIG is directly proportional to the applied magnetic field [45]. The resonance frequency of YIG can be tuned linearly from 500 MHz to 50 GHz [36,38]. Q-factors in the order of 10,000 are realisable with highly polished YIG spheres [35].

3.4.2 YIG-Tuned Oscillator Design

In order to create oscillation in a YIG-tuned device, a negative resistance is required. Essentially, the YIG-tuned LO consists of three parts [45]:

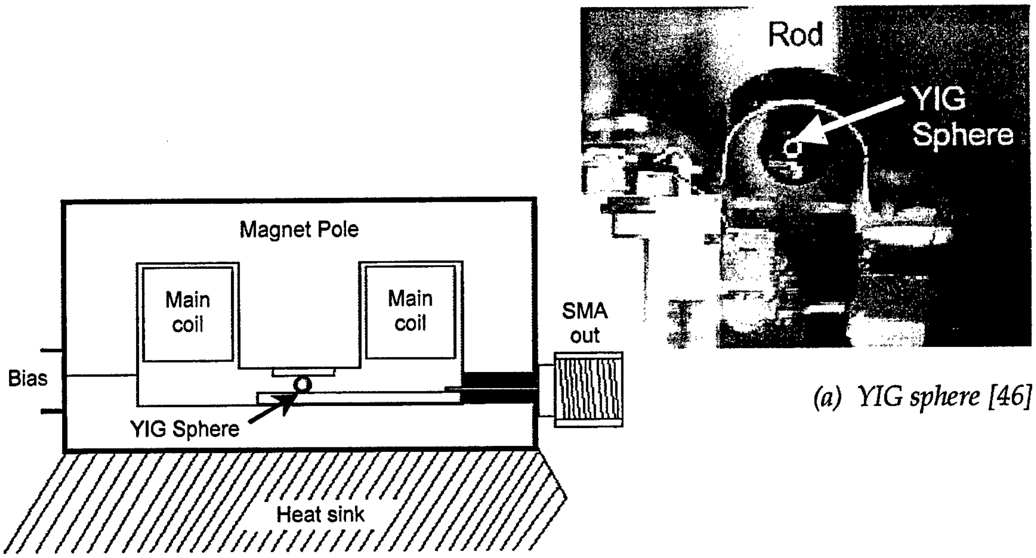
1. YIG sphere to act as a resonator to store energy.
2. A dynamic negative resistance.
3. A structure to produce the variable biasing DC magnetic field.

Figure 9 shows all the typical components in a YIG-tuned LO [35,42,45,46]. The dynamic negative resistance can be obtained with a bipolar transistor [45], a field-effect transistor [45] and Gunn-effect devices [43].

YIG-tuned oscillators have several advantages [45]:

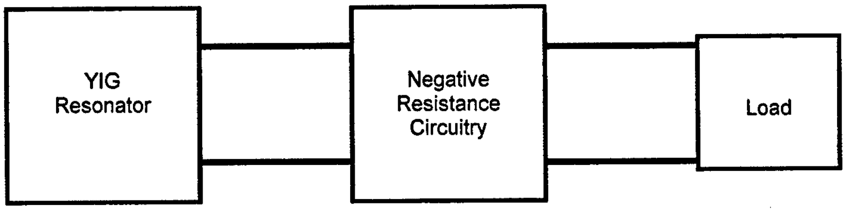
1. Low phase noise due to the high Q-factor achieved in the YIG resonator.
2. Wide operating frequencies over two octaves, i.e. 500 MHz to 50 GHz [36,38].
3. Excellent tuning linearity.
4. High reliability.
5. High output power with an integrated buffer amplifier.

With the operating frequency range from 500 MHz up to 50 GHz, this matches perfectly with military applications such as Electronic Warfare (EW) heterodyne receiver systems. Therefore, YIG-tuned LOs have been widely used in both military and commercial systems [45].



(a) YIG sphere [46]

(b) YIG resonator structure [46]



(c) YIG-tuned oscillator circuit block diagram [45]

Figure 9: YIG-tuned oscillator technology.

3.5 Gunn-Effect Oscillator Technology

In 1963, J.B.Gunn found random noise-like oscillations in n-type GaAs semiconductor materials upon reaching a threshold level of the applied field [47-52]. The underlying cause of the oscillations is due to the transferred-electron mechanism, generally referred to as the Gunn effect [47]. Such transferred-electron devices are known as Gunn diodes [47-58].

3.5.1 Gunn Diode

In order to understand the principle of operation of a Gunn diode in reference to the Gunn-effect oscillator technology, it is necessary to consider the electron drift velocity (current) versus applied electric field (voltage) relationship in n-type GaAs, and also InP, materials [47-58]. This relationship is illustrated in Figure 10.

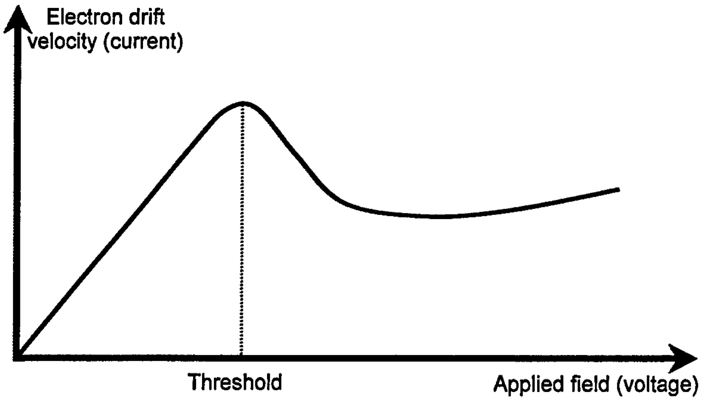


Figure 10: Relationship between electron drift velocity and applied electric field in n-type GaAs or InP materials [47-58].

Referring to Figure 10, the Gunn diode behaves like a passive resistance below a threshold field of approximately 0.32 V/μm for GaAs. However, above this threshold the electron drift velocity decreases with increasing applied field. This produces negative differential mobility or dynamic resistance as required for constructing oscillators [47-52].

The negative dynamic resistance is primarily determined by the characteristics of the semiconductor material used in the Gunn diode, not by external circuitry [47-52]. A Gunn diode can self-oscillate due to resonance of the device parasitic, but this self-oscillation cannot be controlled.

3.5.2 Gunn Oscillator Design

Having a negative dynamic resistance from a Gunn diode, it can be coupled to a YIG resonator as shown in Figure 9(c) to form an oscillator [43,49]. However, YIG-tuned resonance is restricted to 50 GHz placing a limit on the maximum frequency of YIG-tuned Gunn LOs.

In order to make full use of the negative dynamic resistance from Gunn diodes, waveguide resonant cavities are utilised to realise LOs up to 110 GHz [49]. Figure 11 shows a basic waveguide resonant cavity design for high frequency Gunn LOs [49]. The cavity resonance frequency becomes the oscillation frequency, which can be tuned by either metal or dielectric screws, as can be seen in Figure 11. Waveguide resonant cavities can be designed to exhibit a high Q-factor, in the order of thousands [47-58], to give Gunn LOs their low phase noise at millimetric frequencies.

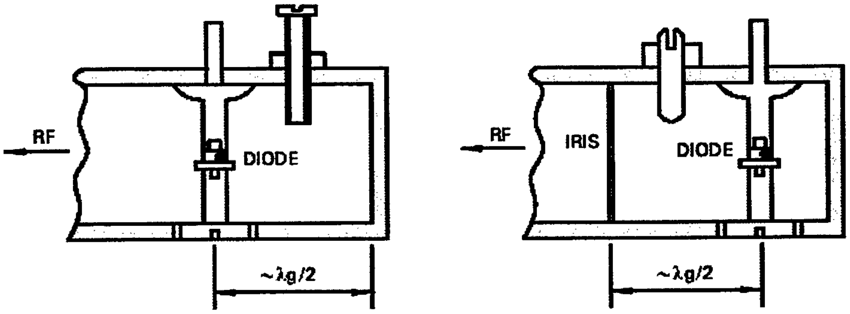


Figure 11: Basic waveguide resonant cavity design for Gunn oscillators [49]

Advantages of Gunn LOs include [49]:

1. Low phase noise.
2. Highly reliable and compact.
3. Low power consumption.
4. High operational frequencies up to 110 GHz.

3.6 Summary

Combining the frequencies of quartz LOs, frequency synthesisers, YIG-tuned LOs and Gunn LOs, heterodyne receivers for signals ranging from low MHz up to 110 GHz can be implemented in EW applications. In comparison, state-of-the-art radio astronomy observatories aim to detect signals up to 1 THz. In reference to EW applications, potential hostile threats now occur in the 35 GHz and 94 GHz windows, and therefore both YIG-tuned and Gunn LOs are critical for millimetric heterodyne receivers.

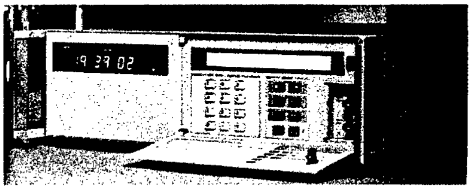
4. Commercial LO Performance

The various types of local oscillator (LO) technologies were reviewed in the last section. A selection of current commercial-off-the-shelf (COTS) products are selected, whose specifications are extracted and summarised in the process of deriving a performance benchmark for the development of photonic LOs. Manufacturer specifications vary and so not all relevant parameters are be available.

4.1 Cesium Oscillators

The best cesium (Cs) oscillator currently available is the Agilent 5071A Primary Frequency Standard [59]. Its specifications are:

Frequency:	5 MHz and 10 MHz
Tunability:	Fixed
Operating temperature:	0 - 50 °C
Amplitude:	>1 Vrms into 50 Ω
Frequency accuracy:	$\pm 1\text{x}10^{-12}$
Frequency stability:	$\pm 1\text{x}10^{-13}$
Phase noise:	
1 Hz	≤-85 dBc/Hz
10 Hz	≤-125 dBc/Hz
100 Hz	≤-135 dBc/Hz
1 kHz	≤-140 dBc/Hz
10 kHz	≤-145 dBc/Hz
100 kHz	≤-145 dBc/Hz
Dimensions:	133.4×425.5×523.9 mm^3 (H×W×D)
Weight:	30 kg



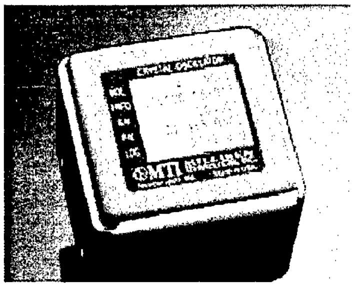
This is a highly accurate frequency standard, but its size and weight limit its application to synchronisation of telecommunications networks or calibration laboratories.

4.2 Quartz Oscillators

Both standalone and Global Positioning System (GPS) disciplined quartz oscillators are presented to contrast with each other.

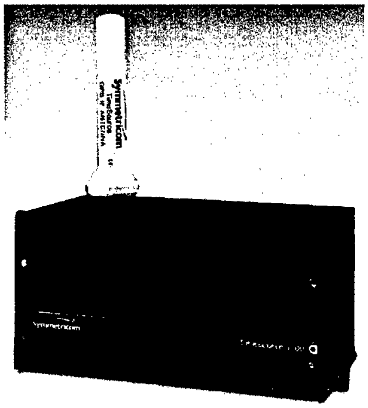
4.2.1 Standalone Quartz Oscillator

A 260 Series Double Oven Controlled Crystal Oscillator (OCXO) from MTI-Milliren Technologies is selected as it has performance specifications comparable to a Rubidium oscillator [60]. This OCXO is compact and low cost making it ideal as a reference oscillator for frequency synthesis in many electronic applications. It has these specifications:



Frequency:	32 kHz to 30 MHz
Tunability:	Fixed
Operating temperature:	-30 - 70 °C
Amplitude:	0 to + 13 dBm Sine
Frequency stability:	2x10^{-9}
Phase noise:	
1 Hz	≤-85 dBc/Hz
10 Hz	≤-115 dBc/Hz
100 Hz	≤-130 dBc/Hz
1 kHz	≤-140 dBc/Hz
10 kHz	≤-145 dBc/Hz
100 kHz	≤-145 dBc/Hz
Dimensions:	38.1×50.8×50.8 mm^3 (H×W×D)

4.2.2 GPS Disciplined Quartz Oscillator



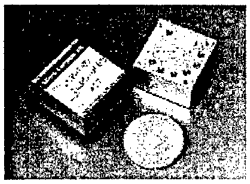
GPS is a constellation of satellites, which is used for navigational purposes. Timing information can be extracted from signals received from these GPS satellites, which can be utilised to discipline a quartz oscillator.

The Timesource 3100 from Symmetricom [61] is one such GPS-disciplined quartz oscillator, which has Cs-like performance. This model provides 2.048 MHz and 10 MHz outputs, but Symmetricom does not specify their product like other oscillators. The specification simply states that it is suitable as a primary clock for synchronisation of telecommunication networks, directly competing with Cs clocks.

4.3 YIG-Tuned Oscillators

There are a number of suppliers of YIG-tuned oscillators, namely Micro Lambda Wireless Inc., ELVA-1 Company - Millimeter Wave Division, Omniyig Inc., Verticom Inc. and Endwave Corporation. Products from Micro Lambda Wireless Inc. are selected because the company is an agency for a defence investigative service.

The first device selected is MLPB-0608 Miniature Permanent Magnet YIG-tuned oscillator [62]. The specifications are:

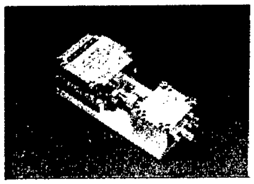


Frequency:	7 GHz
Tunability:	2 GHz
Operating temperature:	-20 - 70°C
Amplitude:	+14 dBm

Amplitude stability: ±1 dB
Frequency stability: 0.002%
Phase noise:
10 kHz ≤-98 dBc/Hz
100 kHz ≤-120 dBc/Hz
Dimensions: 25×25×12.5 mm^3 (H×W×D)

The second device selected is MLPX-2836 Miniature Permanent Magnet YIG-tuned oscillator [63]. The specifications are:

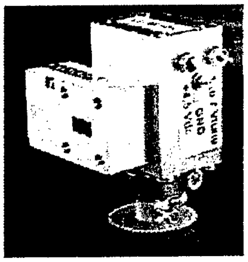
Frequency: 32 GHz
Tunability: 8 GHz
Operating temperature: -20 - 70°C
Amplitude: +8 dBm
Amplitude stability: ±4 dB
Frequency stability: 0.004%
Phase noise:
10 kHz ≤-74 dBc/Hz
100 kHz ≤-94 dBc/Hz



4.4 Gunn Oscillators

There are also a number of suppliers for Gunn oscillators including Nitsuki, Dynex Semiconductor Ltd., Harmonix Corporation, Microwave Device Technology Corporation and QuinStar Technology Inc. HGM Series devices from Harmonix Corporation are selected to present here because they come in frequency ranges up to 110 GHz [64].

Frequency Range (GHz)	Tunability (MHz)	Amplitude (mW)	Frequency Stability (MHz/°C)
7-12.4	500	400	-0.5
26.5-40	500	200	-0.9
90-95	200	40	-6.0



The primary stability problem associated with Gunn oscillators is frequency variation with temperature. A phase-locked loop must be utilised in conjunction with the Gunn oscillator, which acts as a voltage-controlled oscillator, to improve its frequency accuracy and stability.

4.5 Summary

There are commercial oscillators available with operating frequencies up to 110 GHz providing extensive frequency coverage as LOs in heterodyne receiver architecture. Specifications from typical devices were selected and presented in this section. The future development of photonic LOs should at least match these performance measures from current state-of-the-art technologies.

5. LO Specifications in Electronic Warfare Receivers

In addition to specifications of commercial-off-the-shelf (COTS) local oscillators (LOs), various examples of unclassified LO specifications are presented in this section. Typically, many Electronic Warfare (EW) applications utilise frequency synthesisers as LOs to get frequency coverage, whose reference signals can be provided by reliable low-frequency quartz and yttrium iron garnet (YIG) oscillators.

5.1 Example 1

A 2815-4415 MHz frequency synthesiser [65]:

Frequency range:	2815 - 4415 MHz
Frequency tuning resolution:	1 MHz
Frequency accuracy:	±0.1 MHz
Output power:	-3±3 dBm
Phase noise:	
10 kHz	≤-60 dBc/Hz
100 kHz	≤-95 dBc/Hz
Operating temperature:	-20 - 85°C
Reference frequency:	10 MHz external

5.2 Example 2

A 2415 MHz frequency synthesiser [65]:

Frequency:	2415 MHz
Output power:	0±2 dBm
Phase noise:	
10 kHz	≤-90 dBc/Hz
100 kHz	≤-110 dBc/Hz
Operating temperature:	-20 - 85°C
Reference frequency:	10 MHz external

In both Examples 1 and 2, the 10 MHz reference input would be high-quality and low-cost quartz oscillators.

5.3 Example 3

Avitronics is a supplier of airborne Electronic Warfare (EW) solutions such as emitter location system, electronic surveillance payload and helicopter self-protection system [66]. It also supplies LOs suitable for military airborne applications [66].

1. Avitronics LO modules - P/N 760301-00000 [66]:

Frequency range:	8 GHz ± 10 MHz 12 GHz ± 10 MHz
Output power:	>+15 dBm
Phase noise:	
100 kHz	≤-70 dBc/Hz

2. Avitronics dielectric resonant oscillator - P/N 760308-00000 [66]:

Frequency range:	6 GHz ± 10 MHz
Output power:	>+13 dBm
Phase noise:	
100 kHz	≤-70 dBc/Hz

3. Avitronics dielectric resonant oscillator - P/N 760309-00000 [66]:

Frequency range:	8 GHz ± 10 MHz
Output power:	>+12 dBm
Phase noise:	
100 kHz	≤-70 dBc/Hz

5.4 Example 4

A 42 GHz phase-locked oscillator [67]:

Frequency:	42 GHz
Output power:	16 dBm
Operating temperature:	0 - 50°C
Reference frequency:	100 MHz internal
Reference stability:	±3 ppm
Reference input power:	3±3 dBm
Spurious response:	-60 dBc
Harmonics:	-40 dBc

5.5 Example 5

A 50 GHz phase-locked oscillator [67]:

Frequency:	50 GHz
Output power:	19 dBm
Operating temperature:	0 - 50°C
Reference frequency:	100 MHz internal
Reference stability:	±3 ppm
Reference input power:	3±3 dBm
Spurious response:	-60 dBc
Harmonics:	-40 dBc

5.6 Example 6

An 80 GHz phase-locked oscillator [67]:

Frequency:	80 GHz
Output power:	13 dBm
Operating temperature:	0 - 50°C
Reference frequency:	100 MHz internal
Reference stability:	±3 ppm
Reference input power:	3±3 dBm
Spurious response:	-60 dBc
Harmonics:	-40 dBc

5.7 Summary

Although the examples listed in this section are by no means exhaustive, it can be said that there is no common theme in the examples of LO requirements in EW receivers. It is a good indication that LO requirements in EW heterodyne receivers are application specific. This makes it difficult to extract a performance benchmark to evaluate the photonic LOs under development. Taking into account that trade-offs between various parameters are necessary depending on the applications, a possible benchmark is listed below:

Benchmark to evaluate photonic LOs

Amplitude:	As high as possible
Amplitude stability:	≤0.5 dB
Frequency range:	DC - 110 GHz
Tunability:	
Coarse tuning	≤1 GHz steps
Fine tuning	≤1 MHz steps
Frequency accuracy:	≤100 kHz
Frequency stability:	≤1 ppm
Phase noise:	
1 Hz	≤-80 dBc/Hz
1 kHz	≤-100 dBc/Hz
100 kHz	<-120 dBc/Hz

6. Photonic LO Techniques

In this section, an overview of various photonic techniques to generate local oscillator (LO) signals is presented. Their advantages and disadvantages will be highlighted. Photonic technology offers unique properties including low attenuation, wide bandwidth and immunity to electromagnetic interference for Electronic Warfare (EW) systems in which distribution of LO signals to multiple locations is required in addition to photonic signal processing.

6.1 Analogue Modulation

Direct analogue modulation of a laser diode or by using an electro-optic modulator is not really a signal generation technique. An existing electrical LO signal is converted into a modulated optical carrier. This solution is commercially available and commonly utilised for signal distribution [69]. This technique is limited by the modulation bandwidths of the laser and modulator for direct and external modulation, respectively.

6.2 Optical Frequency Heterodyning

The easiest and most efficient method of generating radio frequency and up to sub-millimetre-wave signals in the optical domain is by mixing two single-mode lasers, i.e. using the beat signal created from the optical frequency difference [70,71]. This technique is known as optical frequency heterodyning. The output of the lasers can be combined through a simple optical coupler and the mixing occurs at the photodetector. Frequency generation from DC to 110 GHz is commercially available [70]. Generation of 1 THz has been demonstrated as reported with special detectors [71]. This technique offers very wide tuning range, but the upper limit of the frequency range is determined by the bandwidth of the detector. Frequency stability can be very poor due to the drift in laser wavelengths caused by the environmental parameters. Laser wavelength locking techniques must be employed to counteract frequency drift.

Optical frequency heterodyning only produces the LO signal after mixing occurs at the photodetector, i.e. the LO signal is not modulated on the optical carrier. This is a disadvantage in photonic receiver architecture where the LO signal is required to be modulated on the optical carrier [8,12].

Commercial products, such as the OMS-2010 Optical Microwave Systems from Lightwave Electronics Corporation [70], are targeted at the market for modulation response measurements.

6.3 Optoelectronic Oscillator

Researchers at the Jet Propulsion Laboratory, California, championed a solution, referred to as optoelectronic oscillators (OEOs) [72-74], to generate spectrally pure radio frequency, microwave and millimetre-wave signals. The structure of an OEO is as shown in Figure 12.

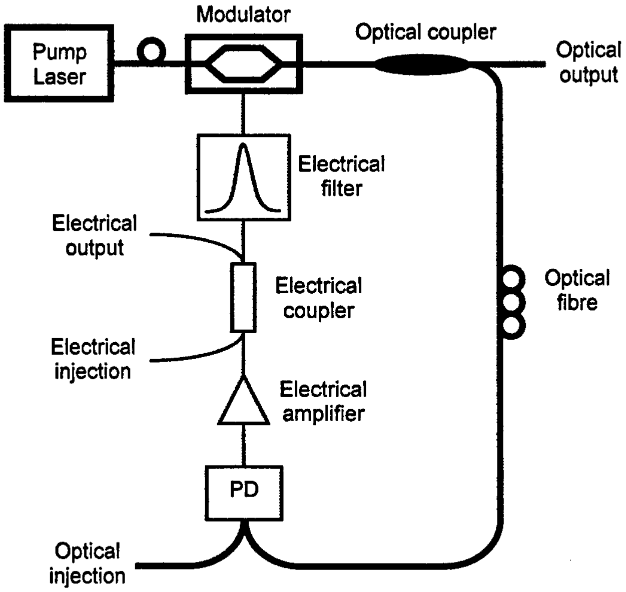


Figure 12: An optoelectronic oscillator [72-74].

In the OEO shown in Figure 12, part of the output is detected and then amplified, filtered and fed back as the modulation input into the modulator. If the modulator is properly biased to achieve phase matching condition and the gain of the feedback loop is correctly chosen, then oscillation can be sustained [72-74]. The desired LO signal is generated in both electrical and optical domains. Injection locking can be applied in both the electrical and optical domains, making the OEO extremely useful as a photonic clock recovery device for telecommunication systems [75,76].

This optoelectronic technique is able to generate signals with excellent spectral purity, i.e. low phase noise, independent of oscillation frequency [72]. This is because the feedback loop acts as a high Q-factor resonator enhancing the spectral purity. However, the tuning speed of the OEO is dependent on the Q-factor. Having a high Q-factor will mean that the energy stored in the resonator would take longer to get dissipated, and thereby limit the tuning speed from one frequency to another.

If fast tuning speed is not a requirement, then a long length of optical fibre can be used to improve frequency stability. The long ring resonator length defines a comb of evenly spaced frequency reference which the electrical filter can be tuned to lock on to. It is worth noting that the optical fibre forming the feedback loop can vary with environmental parameters altering the frequency reference of the OEO. However, this can be minimised by thermal compensation and vibration isolation management of the complete OEO.

The oscillation frequency of the OEO is restricted by the modulation bandwidths of both modulator and photodetector. So it is possible to generate frequencies from DC up to 100 GHz. Various potential applications for the OEO include clock recovery, photonic voltage-controlled oscillator in a phase-locked loop configuration, photonic signal mixing, carrier distribution, frequency multiplication, comb frequency and pulse generation [72,73]. Due to its simplicity and excellent performance, the OEO technology is a promising LO solution for Electronic Warfare (EW) applications. However, environmental aspects must be considered for such an LO solution to be used on military platforms.

6.4 Injection Locking

Frequency synthesis utilising injecting locking has one common theme; it uses optical frequency heterodyning [77-79]. However, locking to a reference signal minimises the frequency stability problems associated with optical frequency heterodyning.

The technique described in Reference 77 demonstrated a solution to generate signals up to 60 GHz using an electrical injection locking reference covering 4-14 GHz. However, significant environmental changes will cause a drift in the optical frequencies and thereby forcing the whole system to fall out of the small locking range.

Injection locking, as described in Reference 77, can be considered as frequency multiplication of the microwave reference. Therefore, the reference phase noise is also multiplied and transferred to the signal generated.

6.5 Photonic Phase-Locked Loops

Photonic phase-locked loop [14,80,81] enables the output, resulting from optical frequency heterodyning, to be phase-locked to a stable microwave reference signal. Optical injection phase-locked loop can be used to improve the locking range of injection-locked photonic LO by tenfold [77,80].

Mostly, it has been the radio astronomers that have exploited photonic phase-locked loop techniques to generate and distribute LO signals to radio telescope arrays [14,81]. Radio astronomy requires special and careful consideration of LO phase noise, which requires complex hardware for photonic phase locking. Their complexity may not be suitable for EW systems. Compact photonic phase-locked loops are required for EW applications.

6.6 Photonic Short Pulse Generation

Photonic short pulse generation [82-84] has the potential to be utilised in LO applications. Mode-locking techniques to laser cavity modes ensure amplitude and frequency stability [82-84]. However, tunability of pulse repetition rate is limited due to fixed cavity modes.

In general, the electrical spectrum of a pulse train consists of harmonics at multiples of the fundamental frequency, i.e. the pulse repetition rate. Therefore, photonic short pulse generation can be utilised for synchronous distribution of multiple LO signals, whose frequencies are multiples of the pulse repetition rate. The extraction of the LO signals from the pulse train can be performed in both optical and electrical domains.

In the optical domain, microwave photonic filtering [9] can be used to select the LO frequency, which remains modulated on the optical carrier. In the electrical domain, the pulse train must be detected first with a high-speed photodetector and the LO frequency would then be selected in the electrical domain.

Research into photonic short pulse generation mainly focuses on applications in telecommunications [82-84]. Its potential as a technique to distribute LO signals should be investigated. Another application for short pulse generation is in photonic analogue-to-digital and digital-to-analogue conversion [85]. Ability to perform photonic digital-to-analogue conversion would make photonic direct digital synthesis possible [86], which can be applied to generate photonic LO signals.

6.7 Summary

Photonic LO development is still in its infancy, but there is great potential in generating signals from near DC and up to 1 THz. As far as EW applications are concerned, the optoelectronic oscillator concept is the most promising. Other techniques such as injection locking and photonic phase-locked loop still require further development to make them suitable for EW applications. Photonic LOs must meet stringent military operating conditions from -60 to +90 °C, and there has been no report on how these photonic LOs perform under military operating conditions.

7. Conclusions

Local oscillator (LO) requirements in Electronic Warfare (EW) heterodyne receivers are application specific. Design trade-offs are often required. Ideal properties, which would be nice to have in LO design, are:

1. Amplitude stability.
2. Wide tunability.
3. Frequency accuracy and stability.
4. Low phase noise.

For EW systems on airborne platforms, size and weight matter. This is where current technologies such as yttrium iron garnet (YIG) tuned and Gunn oscillators have the advantage. These technologies cover a frequency range from 500 MHz up to 110 GHz, which is required because potential hostile threats can now occur in the millimetre-wave range, i.e. 35 and 94 GHz windows. Gunn oscillators do have stability problems with varying operating temperature.

Photonics technology has the potential to be applied to develop LOs operating from near DC to 1 THz. Issues concerning frequency accuracy and stability, and phase noise in photonic LOs require further investigation.

LO requirements for state-of-the-art EW systems in operation remain classified. It is therefore difficult to compile a benchmark to evaluate photonic LO under development for EW applications. Data extraction from both commercial-of-the-shelf LOs and unclassified EW receivers is the next best approach. A possible benchmark is summarised below given that trade-offs between various parameters are necessary and they are application specific.

Benchmark to evaluate photonic LOs

Amplitude:	As high as possible
Amplitude stability:	≤0.5 dB
Frequency range:	DC – 110 GHz
Tunability:	
Coarse tuning	≤1 GHz steps
Fine tuning	≤1 MHz steps
Frequency accuracy:	≤100 kHz
Frequency stability:	≤1 ppm
Phase noise:	
1 Hz	≤-80 dBc/Hz
1 kHz	≤-100 dBc/Hz
100 kHz	<-120 dBc/Hz

Spurious signals and harmonics generated, if injection or phase locking are used, must be low. Operating temperature must meet the harsh environment that military equipment is exposed to, which can be from -60 to +90°C. However, a less stringent temperature specification can be -20 to +80°C.

The benchmark extracted and listed in this report may be difficult to meet given that photonic LO development is still in its infancy. However, trade-offs between various parameters are possible. If photonic LOs are to replace current commercial-off-the-shelf (COTS) technologies, such as YIG-tuned and Gunn oscillators, then they have to out-perform these current technologies or provide significant other benefits such as reducing overall system cost or complexity.

If photonic LOs were to be used on airborne platforms, other issues that will have to be considered and investigated are vibration effects and acceleration sensitivity associated with these platforms, which are known to degrade LO phase noise and hence reduce target detection probability [87].

8. Recommendations

Research and development of photonic local oscillator techniques is still in its infancy. Further investigation is required to identify the best technique that meets the set benchmark to satisfy the requirements for Electronic Warfare applications. The development of photonic LOs must be done in conjunction with researchers and engineers working on EW solutions for millimetric threats.

9. Acknowledgement

The author would like to acknowledge Mr. Geoffrey Knight of the Electronic Warfare & Radar Division, DSTO Edinburgh, Australia, for the endless stimulating discussions on the topic of local oscillators in Electronic Warfare systems. Without his help, this report would not have been completed.

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19. ABSTRACT

Local oscillators (LOs) are required whenever heterodyning is utilised in receiver architectures to convert high-frequency signals to an intermediate-frequency (IF) spectrum for ease of processing. Utilisation of the heterodyning technique includes applications ranging from Electronic Warfare (EW) to radio astronomy. While EW involves the interception and exploitation of signals across the complete electromagnetic (EM) spectrum, the range of frequencies of interest in this report is from near DC and up to millimetre wave (~110 GHz). Radio astronomy shares similarities with EW in the detection of wideband EM signals ranging from radio and up to sub-millimetric frequencies.

This technical report focuses on the requirements of LOs in EW receiver systems. In particular, LO technologies including frequency synthesisers, quartz, yttrium iron garnet (YIG) and Gunn-effect electronics will be discussed in order to derive a suitable benchmark, in terms of tunability, amplitude accuracy and stability, frequency accuracy and stability, and phase noise level, for the development of photonic LOs.