LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
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Technical Note	**LIGO-T10004-61-v1**	2010/09/14

40m RF System Upgrade 2010

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1 Overview

The 2010 upgrade of the 40m will modify the interferometer optical layout so that it represents more faithfully the latest Advanced LIGO configuration [2].

One of the main changes from the old configuration, is the use of lower modulation sidebands: 11 MHz and 55 MHz. Almost all the parts of the RF system will have to be upgraded.

The main changes will interest the following subsystems:

- **phase modulation**: a new, single, broadband EOM
- **frequency generation**: modulation and demodulation signals generated by a new dedicated unit
- **signal demodulation**: new, single, signal demodulation unit, including 3rd harmonic demodulation
- **photodetectors**: resonant photodetector with 2mm photodiodes

This document describes the design and construction of the modulation/demodulation system. The upgrade of the photodetectors is presented separately in LIGO DOC T1000209.

All the material related to the development of the new RF System for the 2010 40m Upgrade is available in the 40m SVN under the path `https://nodus.ligo.caltech.edu:30889/svn/trunk/docs/upgrade08/RFsystem/`

2 RF System Design

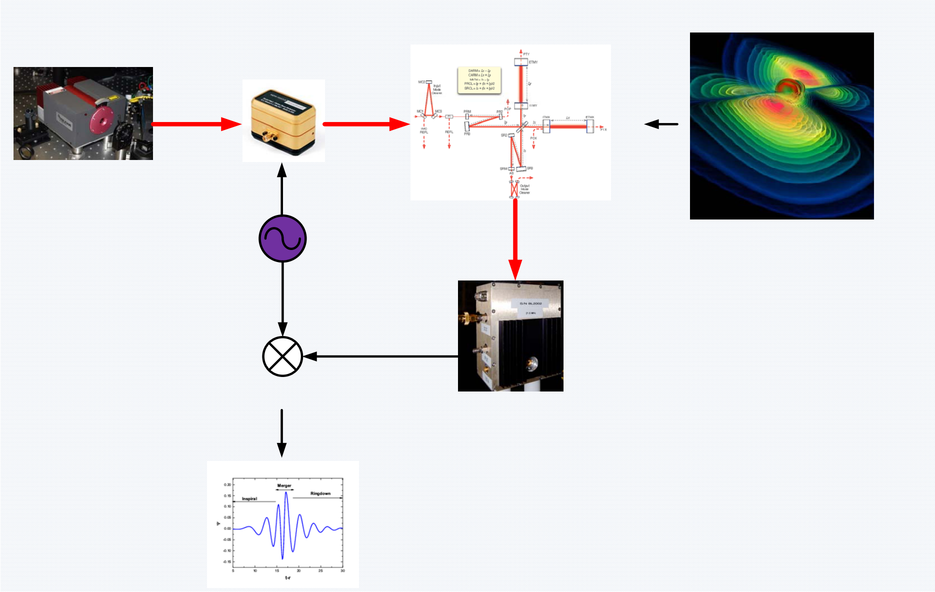


Figure 1: RF System sartoon.

The RF system is made of three parts:

1. The first part of the RF system provides the modulation signals necessary to generate three sets of sidebands: $f_1 = 11\text{MHz}$, $f_2 = 55\text{MHz}$, $f_{mc} = 29.5\text{MHz}$.
2. In the second part, the modulation signals are used to add sidebands on the laser beam at the PSL table.
3. The third part demodulates the signals from the photodiodes with pick-off signals of the modulations generated in the first part.

2.1 Frequency Generation

In the old 40m, the modulations were obtained separately from three Marconi/IFR2023 frequency generators, phase-locked to each other.

Since the required tunability of the modulation frequency is less than few tens of kHz, a wide range frequency generator is superfluous. A dedicated crystal oscillator can perform the task as well, or better. In fact Wenzel crystals guarantee less phase and amplitude noise than a Marconi.

The 40m Upgrade frequencies are generated by only two crystal oscillators: one at 11 MHz, and the other at 29.5 MHz. The first provides directly f_1, and also, indirectly, f_2 via a 5-time frequency multiplier. A Wenzel frequency multiplier guarantees a low relative phase noise between the two sidebands. The second crystal provides f_{mc}.

The modulation signals get amplified and then split in two signals: one to drive the electro-optical modulator (Part 2), the other to be used for demodulation (Part 3).

2.2 Phase Modulation: Broadband EOM

The Mach-Zehnder interferometer scheme used to impose the two phase modulations is abandoned in favour of a single triple-resonant EOM [3, 4]. A KTP 4064 broadband EOM by New Focus is connected to a triple-resonant circuit tuned to the EOM capacitance. The three modulations get combined by a 3-way non-resistive splitter/combiner, and drive the resonant EOM.

2.3 Demodulation

The 40m upgrade will use some of these photodiodes: REFL11, POP11, REFL55, AS55, POP55, POP22, POP110. Additionally 3rd harmonic resonant photodiodes as REFL33, AS33, REFL165, AS165 will be implemented.

To extract the corresponding signals the necessary demodulation frequencies are the 1st, 2nd, 3rd, 5th, 10th, 15th multiples of f_1. While f_1 and f_2 come directly from the Frequency Generation part of the RF system, the other multiples have to be generated by a dedicated demodulation unit.

The function of the unit, is to collect the signals from the Frequency Generation Unit, amplify it, generate the necessary harmonics, and then output the LO signals for the demodulation boards.

2.4 Requirements

The minimum requirements in terms of performances imposed on the RF systems are the following:

- the SNR of the Wenzel oscillators should be preserved as much as possible along the line to the EOM and the demodulators
- the EOM should allow us to tune the modulation depth $\gamma = 0.1 - 0.3$

All the parts should be robust, durable, and time resistant.

2.4.1 Power Levels

According to the commercial specs, the KTP 4064 EOM should have an efficiency $\beta = 13$ mv/rad. In reality, the best we've measured so far is about 9 mV/rad (see [3]). Since we did not measure for β at the time of the initial design, we relied on the specs. Based on that, we calculated the required signal power:

$$V_i = \gamma/\beta = (11 - 33)\ V \rightarrow P_i \approx (28 - 40)\ \text{dBm} \tag{1}$$

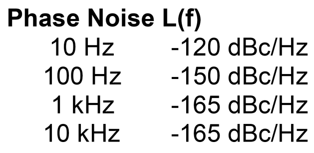
There are not off-the-shelf RF amplifiers available in the market, with low noise figure (≤ 10) and able to output that amount of power, without need of fans for air cooling and large heat sinks. For us the choice was between the Mini-Circuit ZHL-2, and the ZHL-1-2W. The first could offer 28 dBm max power output (1 dB compr.), the second 33 dBm. The ZHL-2 had less heat dissipation, so we picked that.

Since the amplifier could not guarantee more than 30 dBm, we had to require that the EOM resonant circuit provided a gain of 10 dB, at resonance. A prototype of the circuit showed that it was possible [3].

The other contraint was the necessary output power at the demodulation boards [LIGO D990511]. The LO had to have an input power level of 2 dBm.

2.4.2 Phase Noise

The phase noise specified by Wenzel for their crystals is as in the table in Figure 2.



Phase Noise L(f)	
10 Hz	-120 dBc/Hz
100 Hz	-150 dBc/Hz
1 kHz	-165 dBc/Hz
10 kHz	-165 dBc/Hz

Figure 2: Wenzel SC Streamline Crystal Oscillator Phase Noise Specs.

Once that the source's noise is known, the SNR at the output can be calculated as in Appendix A.

2.4.3 Harmonic Distortion

After passing through amplifiers, together with the main line of an oscillation, there are also harmonics of the fundamental frequency. We also investigated the effect of such additional harmonics on the length sensing and control scheme of the 40m Upgrade.

With *Optickle*, we simulated the effect of higher order harmonics by introducing additional frequencies to the main field source vector. We looked at the effect of changing the amplitude of the harmonics on the linearity range of the error signals used to control the interferometer's main DOF.

The additional frequencies circulating in the interferometer start beating with the carrier, the main sidebands and with each other generating signals that couple into the error signals used to control the interferometer.

From an analysis over different order of harmonics, and amplitudes, we set limits on the power relative to that of the carrier. A summary of the results is shown in Figure 3.

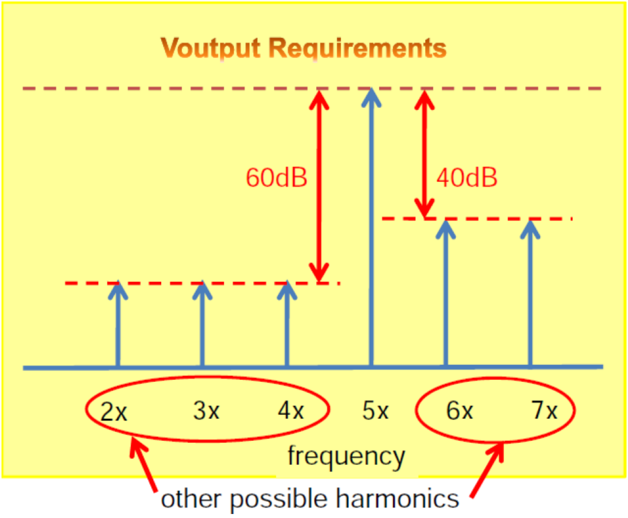


Figure 3: Requirements on maximum relative amplitude between i-th harmonic and f_1 modulation.

Appendix B shows plots of Optickle simulations including high order harmonics.

3 Frequency Generation Unit

A schematic of the Frequency Generation Unit is shown in Figure 4.

Here is a list of the unit's components. Data sheets are attached in Appendix D.

- **crystal oscillators**: 11.065 MHz Wenzel SC Streamline, 29.485 MHz Wenzel SC Streamline;
- **frequency multiplier**: Wenzel 5x LNOM

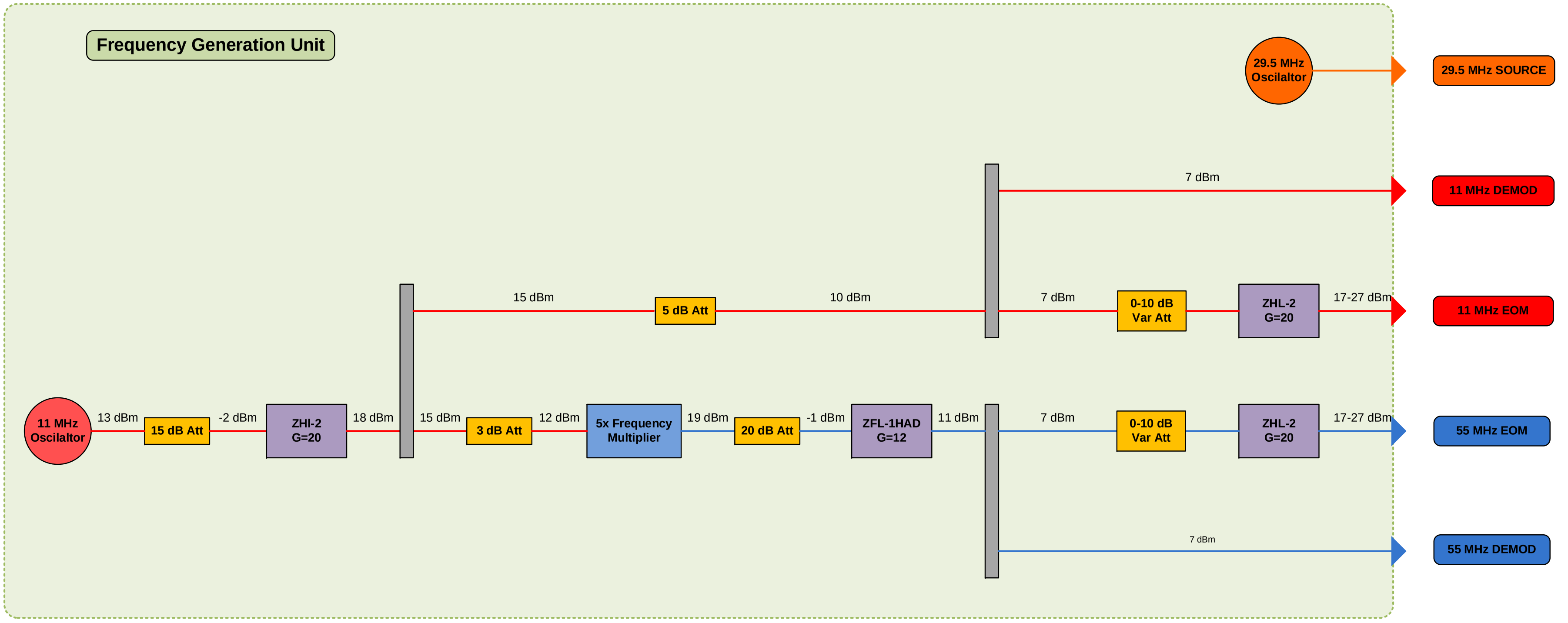


Figure 4: Frequency Generation Unit diagram.

- **amplifiers**: Mini-Circuit ZHL-2, Mini-Circuit ZFL-1HAD
- **power splitters**: Mini-Circuit ZFSC-2-1W-S+
- **attenuators**: Aeroflex-Weinschel manual step attenuator 3007, Teledyne-Cougar UTF0015 voltage controlled attenuator (purchased but currently not installed), Mini-Circuit power attenuators (SMA)
- **voltage regulators**: Wenzel LNVR 18V-to-15V and 28V-to-24V
- **cables**: RG405 (0.086") coated custom made by Cross RF, Inc.
- **RF connectors**: SMA isolated feedthrough connetcors, N-female to SMA-female feedthrough adapters
- **power connectors**: CPC 4-pin power connector
- **switches**: Schurter MSM 19 LA switch

3.1 Powering

The power inputs are: +28V, +18V, GND. A 28-to-24V Low-Noise Voltage Regulator (LNVR) is used to power each of the ZHL-2 amplifiers. The rest of the components gets the 15V DC power from the 18-to-15V LNVR. The LED light of the power switch is also power by one of the 28-24 LNVRs.

3.1.1 Decoupling Capacitors

Bypassing/Decoupling capacitors are attached to the DC power inputs of the ZHL-2 amplifiers. A 10 uF, electrolytic capacitor, and a 0.1 uF ceramic capacitor have been directly attached in parallel to the embedded capacitor at the +24V input connector. The leads were trimmed to avoid their stray capacitance.

The capacitors serve two analogous functions:

- **Decoupling**: The amplification of an input oscillation makes that amplifier absorb a current with the same frequency (more current is absorbed at the crests, less at the bottoms). That becomes a way for the RF signals to couple into the DC line, and thus to affect the other components of the system. The input capacitors are large enough to provide RF filtering at the DC inputs, so that possible RF leakages from other components do not disturb the amplifier.
- **Buffering**: In case of high power amplifier, the required input current fluctuations can be larger and faster than the DC power supply can provide. A large capacitor may provide the necessary buffering.

Two capacitors are needed, one much larger than the other, in order to provide an effective capacitive impedance over a wider frequency range. (Big capacitors have smaller self resonant frequency; that is, they stop to work as capacitors above that point).

Tutorials on how to pick bypassing/decoupling capacitors for high frequency systems can be found in [1, 6].

3.2 Grounding

Good grounding has to be provided to the RF components at all time. Since it is not easy to guarantee even contact between the cases and the support surface, we preferred to provide ground to the components only via the input and output connections.

An isolating board made of Teflon has been used as support surface. The components are attached to the board with screws going through it, and locked by nuts on the other side.

To ensure that the components would not share the ground with the chassis and the electronics rack where the box is installed, all the feedthrough connections have been designed to avoid direct contact with the front and the back panels. G10 plastic rings, hand-made in the campus machine shop, are housed inside the connectors' through-holes. Then Teflon washers are sandwiched between the feedthrough connectors' metal washers/nuts and the front panel.

[To add here pictures of the insulated feedthrough connections]

3.3 Thermal Dissipation

The electrical isolation of the components from the chassis, poses the issue of heat dissipation. In particular, the LNVRs and the ZHL-2 amplifiers tend to overheat without a proper system to sink their heat.

The solution for the LNVRs, was to attach them directly to the back panel, inserting a thin layer of MICA plastic at the interface. MICA was chosen for its high thermal conductivity. To further improve the contact between the panel and the cases, a thin layer of thermal paste was spread on both surfaces of the MICA sheet (Figure 5).

For the amplifiers, L-shaped heat-sinks made bending a 3/8" copper sheet, were installed in between the air heat-sink and the amplifier's case. The short side of the L was put in contact with the side wall of the chassis by inserting a MICA sheet covered with thermal paste between the two. Nylon screws were used to lock the heat sink to the panel (Figure 6).

3.3.1 Temperature Sensor

A temperature sensor was installed on the surface of one of the high power amplifiers. The sensor used was one based on the LM34 transistor, developed at the 40m for tracking the temperature of the interferometer chambers [5].

Before the installation of the heat-sinks on the amplifier, their temperature reached almost 60°C with the box lid closed. With the heat-sinks in place, the temperature was about 35°C with the lid open, and almost 40°C with the lid closed (Figure 7).

At this time, the temperature with all three amplifiers running for a few hours and the box

Figure 5: LNVRs attached to the back panel. Electrical isolation is guaranteed by MICA sheets, G10 through-hole rings, Teflon washers.

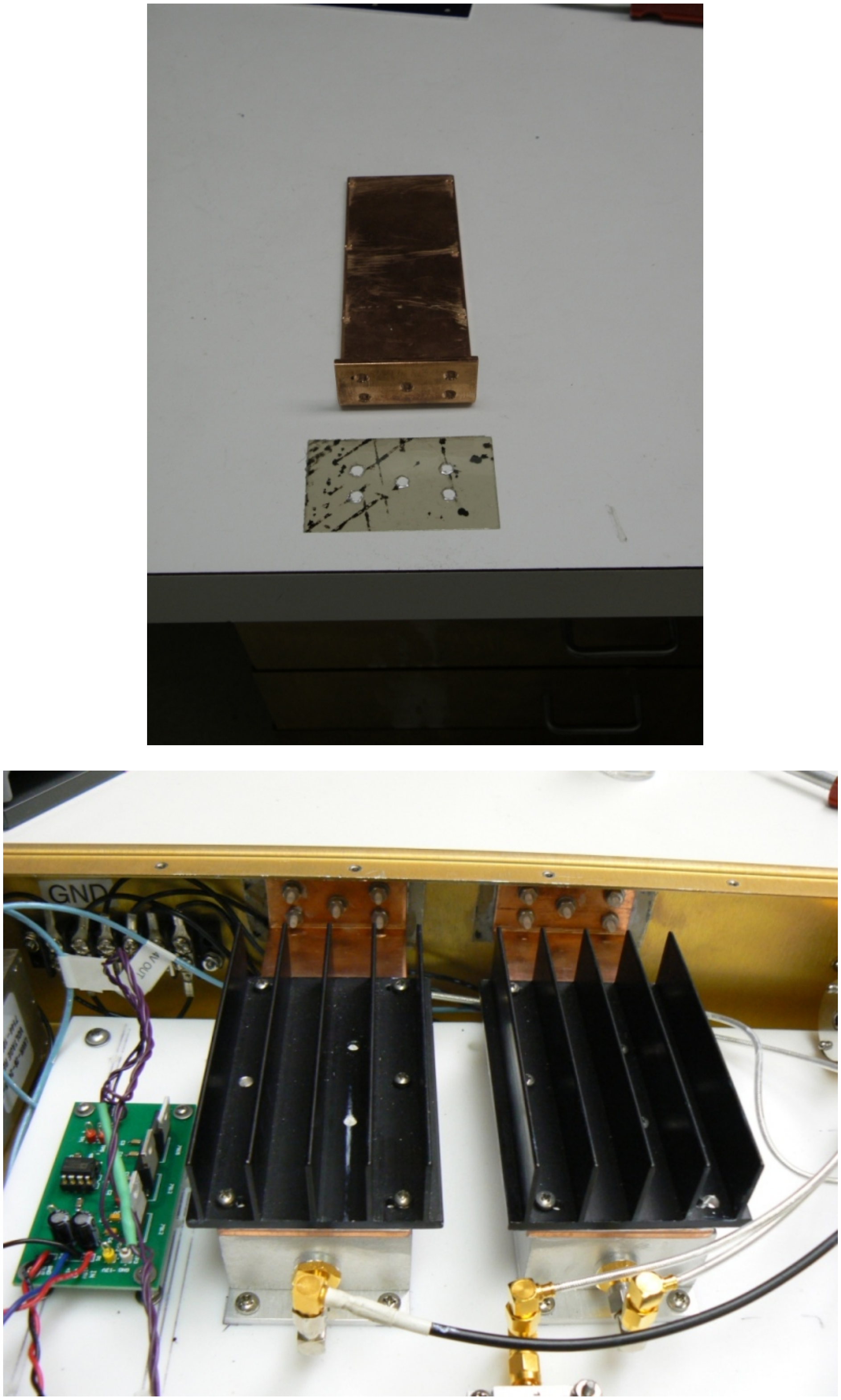


Figure 6: Heat-sinks installed on the ZHL-2 amplifiers. Made of copper, they are electrically separated from the chassis by MICA plastic sheets covered with thermal paste. Nylon screws lock them to the chassis.

closed, hasn't been measured yet. It shouldn't be much higher than 40°C. If it was, the box could be used with the lid open, or new heat-sinks should be designed.

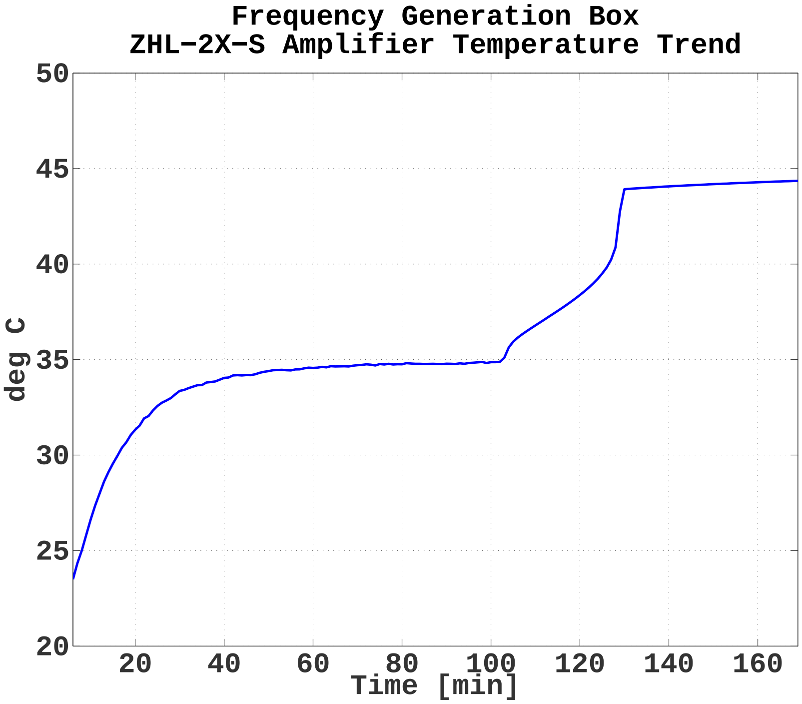


Figure 7: Temperature trend of one of the ZHL-2, with the box lid open, and later closed. The other amplifiers were turned off at the time of the measurement.

4 Oscillator Noise

Noise sidebands in the signal from an oscillator can be measured by homodyne detection. By mixing the source with an auxiliary signal either in phase or in quadrature, one can measure the amplitude modulation or the phase modulation, respectively. In one case the LO is parallel to the RF carrier, and parallel to the amplitude sidebands. In the other, the LO is orthogonal to the RF carrier, and parallel to the phase sidebands (see Figure 8).

The noisy signal from the source can be written as $v_s(t) = A(t)\sin(\omega t + \phi(t))$, with $A(t) = a_0(1 + h(t))$ and $\phi(t)$ describing the amplitude and the phase fluctuations, respectively. The auxiliary, and noiseless signal can be written as $v_a(t) = V_a \sin(\omega t + \varphi)$. Then, the output of the mixer, after band-pass filtering, or DC cut-off, is:

$$v_o(t) = \frac{A(t)V_0}{2}\cos\left(\phi(t) + \varphi\right) \Rightarrow \begin{cases} \frac{A_0 V_0}{2}\sin\phi(t) & \text{for} \quad \varphi = \pi/2 \\ \frac{A(t)V_0}{2} & \text{for} \quad \varphi = 0 \end{cases} \tag{2}$$

Taking the Fourier Transform of both sides of (2), one obtains phase noise, for $\varphi = \pi/2$ and amplitude noise for $\varphi = 0$.

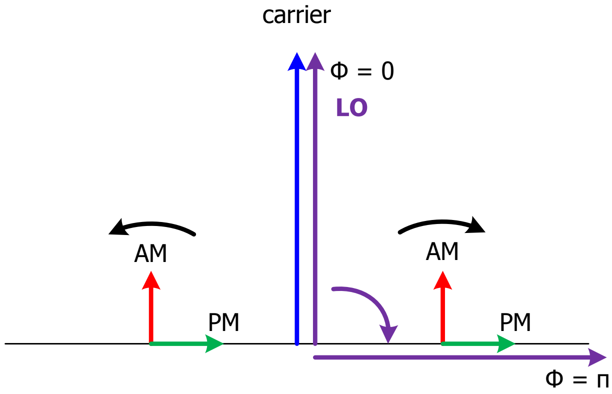


Figure 8: LO parallel or orthogonal to the RF carrier to measure AM or PM sidebands.

4.1 Measuring Phase Noise

The phase noise of an oscillator can be measured by using a second oscillator as a reference. The result is the measurement of the combined phase noise of the pair. If the reference oscillator is much less noisy than that to be measured, then the phase noise can be attributed in full to the first.

The measurement requires the use of a PLL that connects the test oscillator and the reference oscillator. To do that, one has to be able to act as a VCO.

In our case, the oscillator under test is a Wenzel Crystal tuned at about 21.5 MHz. The VCO is a Marconi frequency generator (IFR 2023). The setup for the measurement is shown in Figure 9.

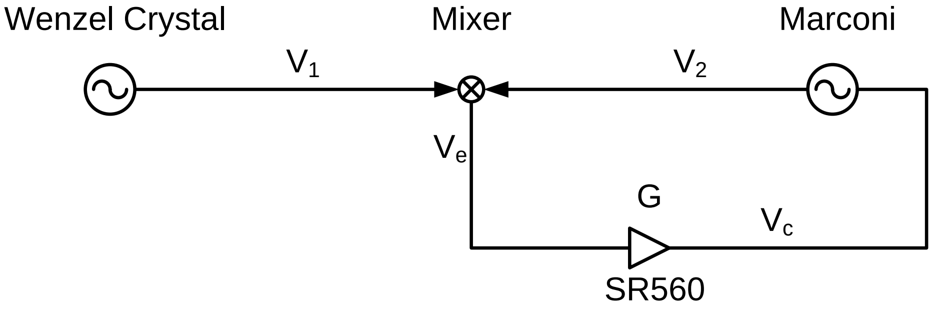
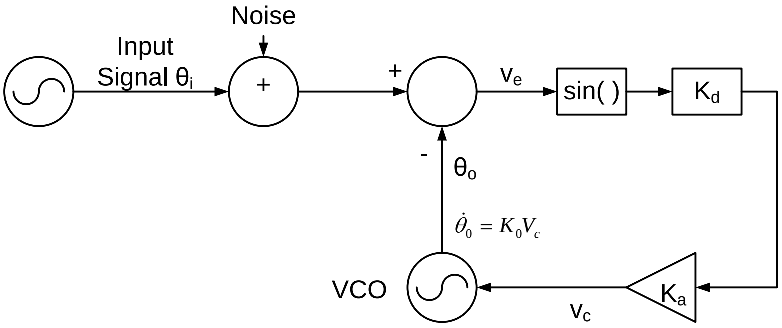


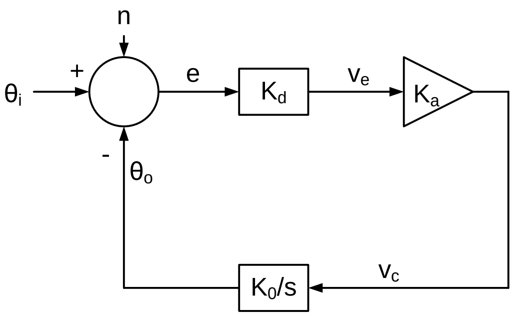
Figure 9: Phase Noise Measurement Setup

Here $V_1(t) = V_{10}\cos(\phi_1(t))$ and $V_2(t) = V_{20}\sin(\phi_2(t)$ are the oscillations from the sources. When hey get mixed, the result is the loop's error signal $V_e(t) = KV_{10}V_{20}\sin(\phi_1(t) - \phi_2(t))$, where K is the mixers gain. An SR560 amplifies the signals by a factor G, and produces the control signal $V_c = GV_e$ that drives the Marconi's VCO.

The diagram representing the PLL is shown in Figure 4.1. In particular in Figure 10(b) the PLL linearity assumption holds, and the loop is assumed to be already locked. The Marconi plays the part of a noiseless VCO, such that the noise is shifted entirely over the oscillator



(a) PLL in time domain



(b) Linearized PLL in s-space

Figure 10: PLL diagrams: noise n, error signal e, control signal v_c, mixer gain k_d, preamplifier gain k_a.

under test. The following relations hold for the locked PLL:

$$
\begin{aligned}
e &= \theta_i - \theta_0 - n && (3)\\
v_e &= K_d v_e && (4)\\
v_c &= K_a v_d && (5)\\
\theta_0 &= K_0/s && (6)
\end{aligned}
$$

The open loop gain is

$$G(s) = \frac{K_a K_d K_0}{s} \tag{7}$$

and it relates the spectrum of the error signal and that of the noise:

$$\hat{e} = \frac{1}{1+G}\ \hat{n}. \tag{8}$$

Since we can measure $\hat{v}_c$, K_d and K_0 separately, and K_a is also known, we can obtain the phase noise:

$$\hat{n} = \frac{1 + K_a K_d K_0/s}{K_a K_d}\ \hat{v}_c \tag{9}$$

4.1.1 Measuring the Calibration

The calibration from phase [rad] to volts is given by K_d. It can be measured with the loop open, by looking a the output of the mixer, v_e. There, a sine appears as a consequence of the mismatch between the frequency of the two oscillators due to the open loop. The peak amplitude V_{pk} of the wave is the voltage change corresponding to a phase of $\pi/2$.

$$v_d = K_d \sin(\phi) \tag{10}$$
$$K_d = v_d(\pi/2) \tag{11}$$

4.1.2 Unit Conversion

$$\delta\phi_{rms}(f)_{[\mathrm{dBc/Hz}]} = 20\log\left(\frac{\sqrt{2}}{2}\delta\phi_{rms}(f)_{[rad/\sqrt{Hz}]}\right) \tag{12}$$

4.2 Measurements

The setup used for the measurement is shown in Figure 11. The Mixer used was the ZFM-3 by Mini-Circuit, with an LO level of +13dBm. The frequency reference was obtained by an IFR2023 frequency generator locked to a Rubidium Frequency Standard.

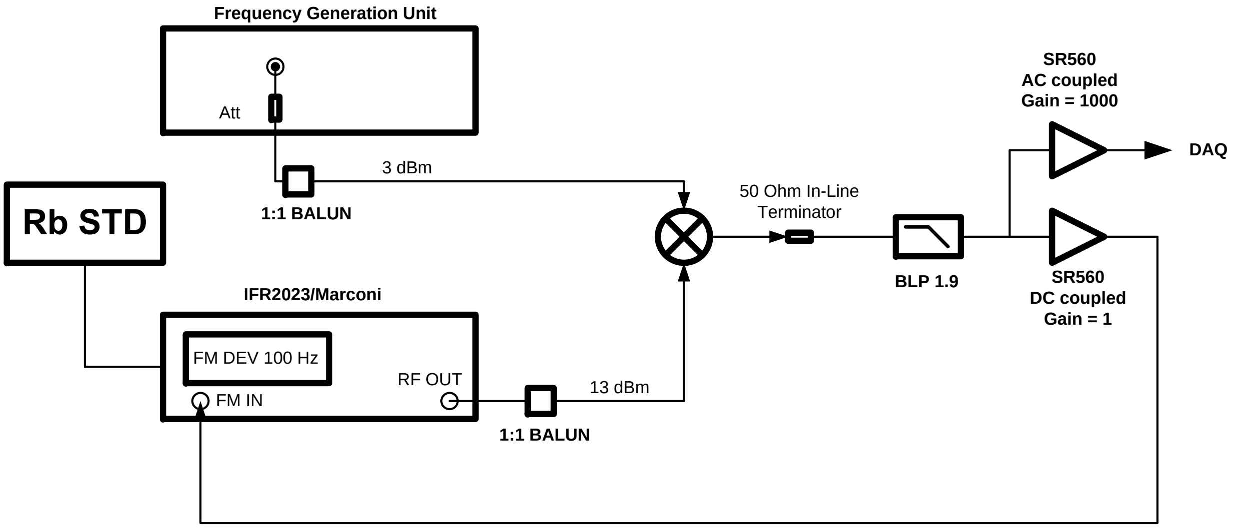


Figure 11: Phase Noise Measurement Setup.

The results of the measurements over all output channels of the Frequency Generation box are shown in the plot in Figure 12.

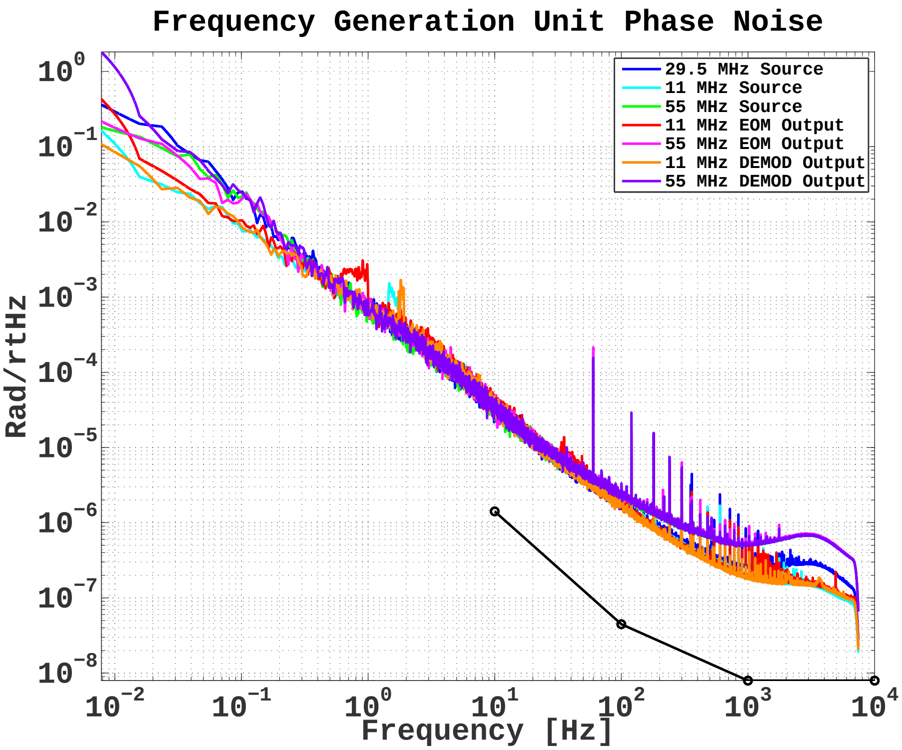


Figure 12: Phase Noise Measurements on the output channels of the RF Frequency Generation box.

4.2.1 Data

The measurement data is located in in the 40m SVN under the path:`/svn/trunk/docs/upgrade08/RFsystem/frequencyGenerationBox/phaseNoise`.

4.3 Measuring Amplitude Noise

The amplitude noise of an oscillator can be measured by homodyning the source signal with itself. The measurement setup is shown in Figure 13.

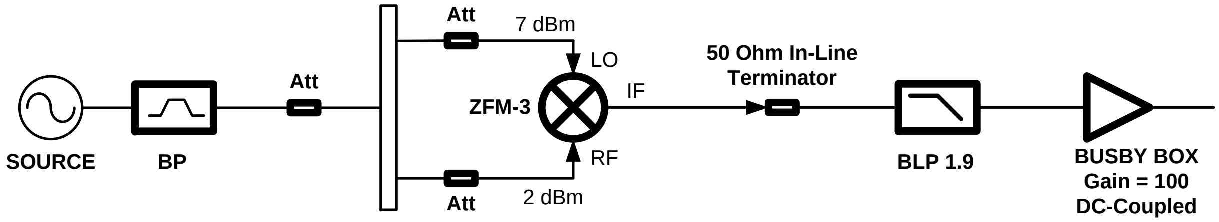


Figure 13: Amplitude Noise Measurement Setup.

The signal is first band-passed, then attenuated and split by two. The outputs of the power splitter are attenuated and mixed. The connection between the splitter and the mixer must have the same length for phase preservation (length difference no longer than 1-2 deg). The output of the mixer is low-passed and amplified by a DC coupled preamplifier.

The calibration factor was measured from the DC output level of the mixer. The spectrum density has to be divided by that factor in order to obtain the proper unit.

The mixer used was by Mini-Circuit and had a LO level of +7 dBm. The preamplifier was the *Busby Box* with low noise at 1 nV/$\sqrt{\text{Hz}}$.

The results of the measurements are shown in Figure 14.

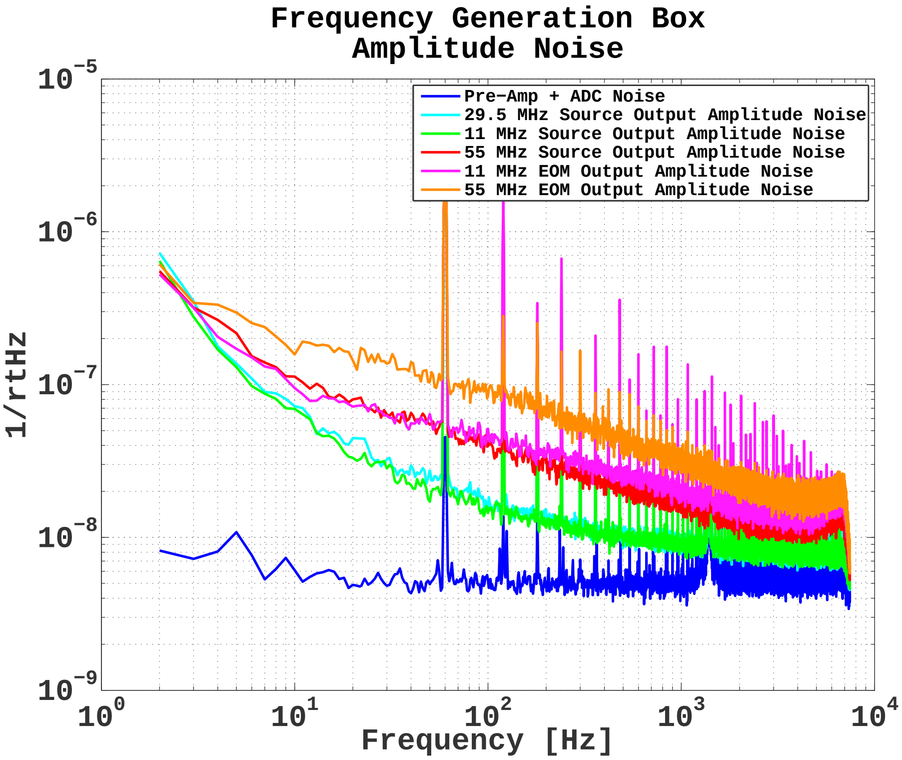


Figure 14: Amplitude Noise Measurements.

4.4 Measurements

The measurement data is located in in the 40m SVN under the path:`/svn/trunk/docs/upgrade08/RFsystem/frequencyGenerationBox/amplitudeNoise`.

5 Frequency Distribution Unit

A schematic of the Frequency Distribution and Demodulation Unit is shown in Figure 15.

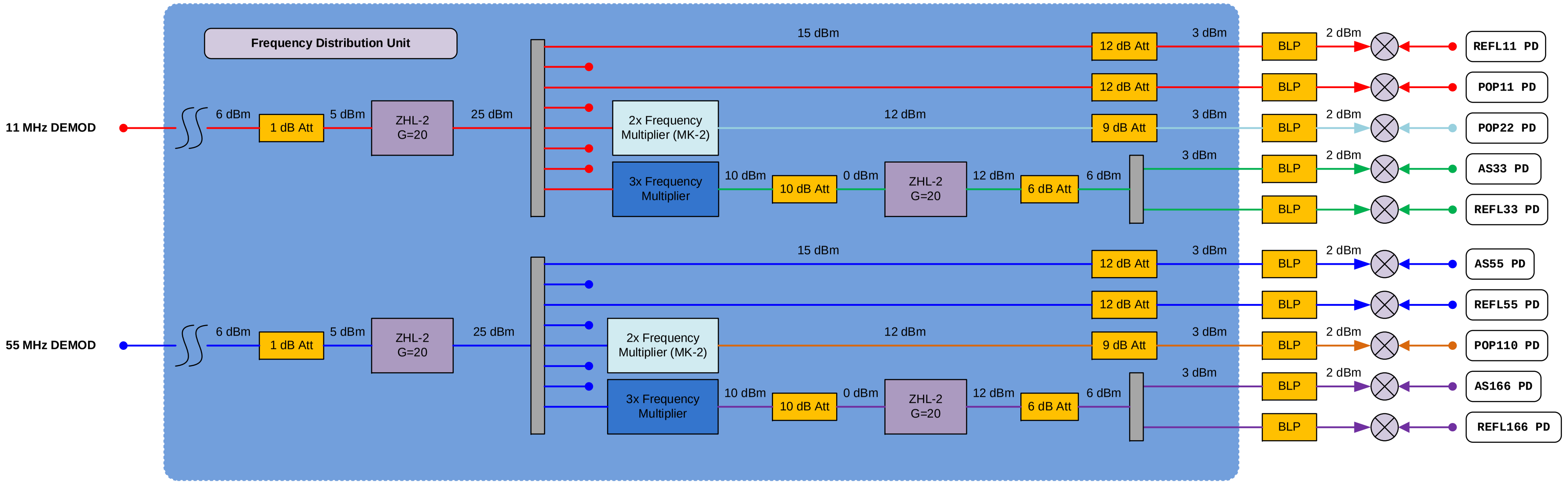


Figure 15: Frequency Generation Distribution Unit diagram.

A Amplifier Noise Figure

The Noise Figure of an amplifier is the ratio, in decibels, of the output of a “real” amplifier to the output of a “perfect”(noiseless) amplifier for the same gain, with a resistor R_s connected in series to the input (Fig. 16).

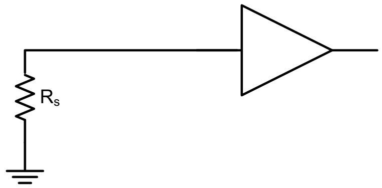


Figure 16: Diagram representing the definition of the Noise Figure.

The Noise Figure does not provides an absolute value of the noise added by an amplifier. It rather expresses noise relatively to that of the Johnson’s noise of the source impedance.

$$\mathrm{NF}(Z_{in} \gg R_s) = 10\log_{10}\left(\frac{4k_B R_s T + v_n^2}{4k_B R_s T}\right) \tag{13}$$

Here’s ho to convert from NF to SNR:

$$\mathrm{SNR_{dB}} = 10\log_{10}\left(\frac{v_s^2}{4k_B T R_s}\right) - \mathrm{NF_{dB}}(R_s) \tag{14}$$

where v_s is the rms signal amplitude, R_s is the source impedance and NF is the noise figure of the amplifier for source impedance R_s.

For example, for the MAX4107 opamp contained in the 40m PD’c circuit, which has a noise $v_n = 0.75nV/\sqrt{Hz}$, and for a 50Ω source impedance, we have $\mathrm{NF}(R_s = 50\Omega) = 2.3\mathrm{dB}$.

A.1 RF Amplifiers

For RF amplifiers, in which the input impedance is matched with the source impedance, both being 50Ω, then the the factor of four in the Johnson’s noise power gets dropped:

$$v_{in}^2 = 4k_B R_s T\left(\frac{Z_{in}}{R_s + Z_{in}}\right)^2 = k_B R_s T \tag{15}$$

The Noise Figure at RF is then *for a typical 50Ω input impedance RF amplifier; i.e. the amplifiers from Mini Circuit*[1]:

$$\mathrm{NF_{amp}^{RF}} = 10\log_{10}\left(1 + \frac{v_n^2}{k_B R_s T}\right). \tag{16}$$

---

[1] Note that the factors of 4 have been dropped from the Johnson’s noise term because of the amplifier’s input impedance. See Horowitx-Hill, pag. 435)

B Effect of Harmonic Distortion on the Interferometer

This plot shows the result of an Optickle simulation of the interferometer. The g_i parameter on the legend measures the *amplitude* ratio between the main signal at 11 MHz and the ith harmonic.

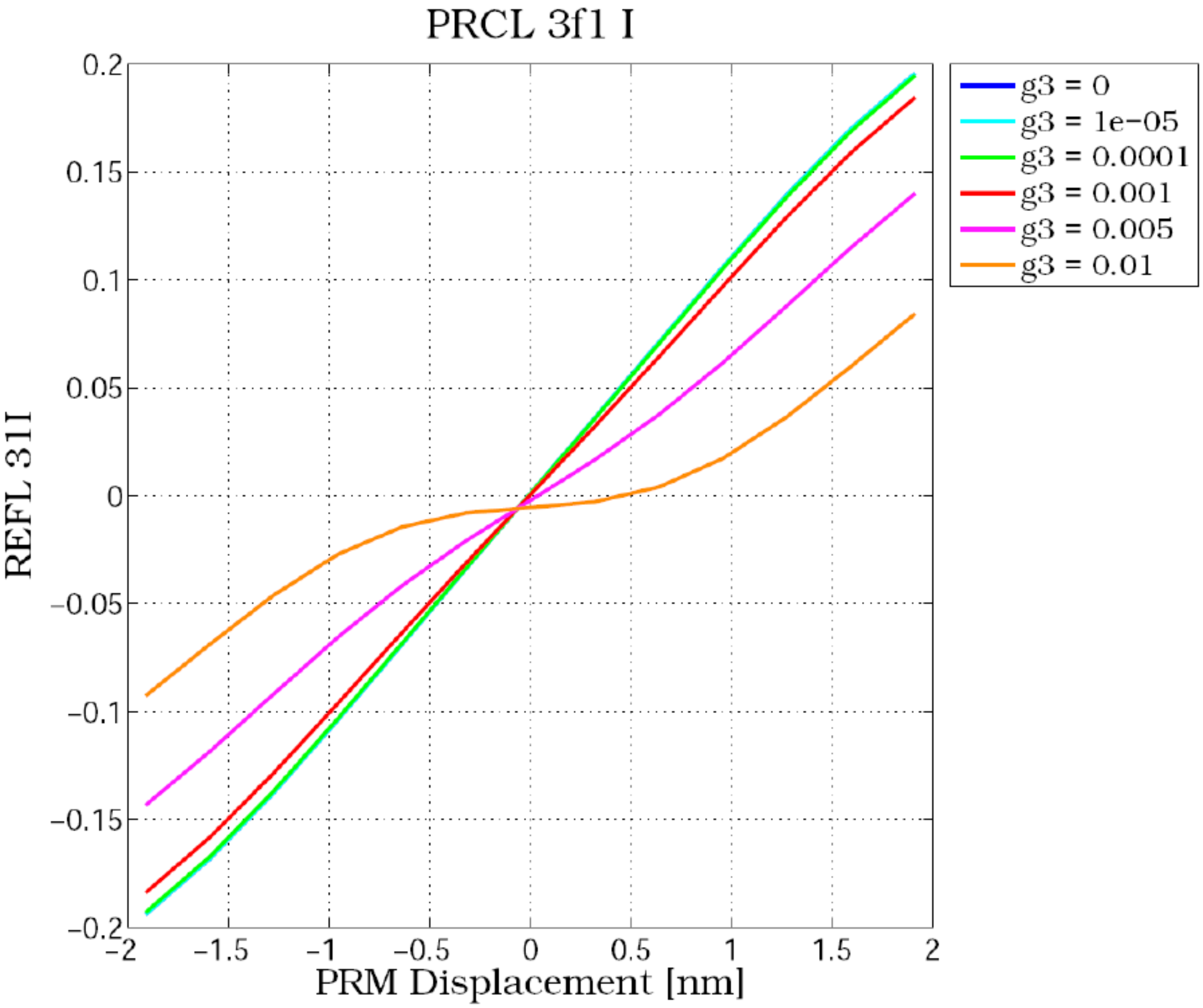


Figure 17: One the proposed error signals for the control of the PRC, PRCL3f1 is plotted. The PRC control signal's gain becomes zero when the 3rd order harmonics is -60dB below the main modulation. The linearity range of the PDH control signals is also reduced.

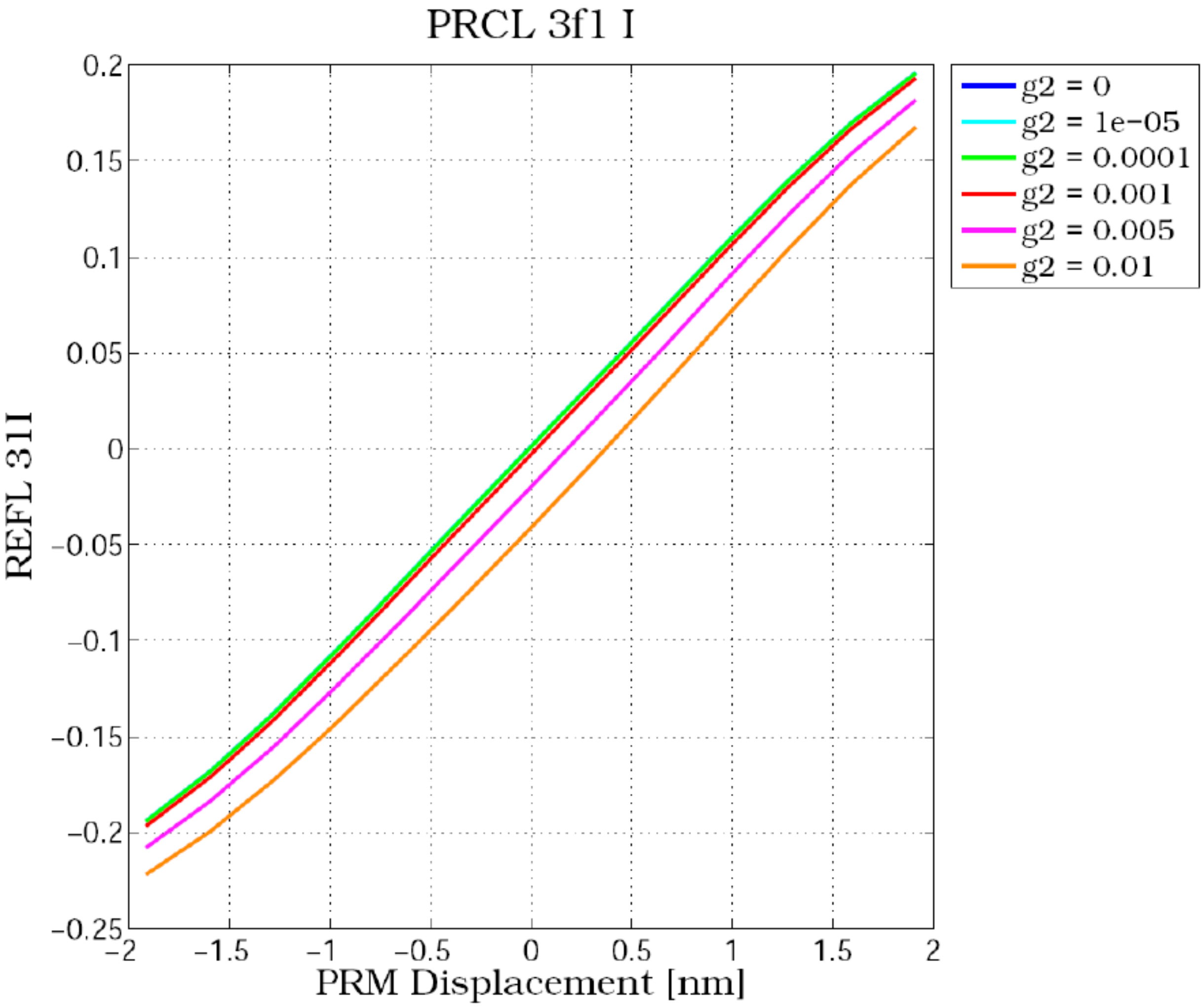
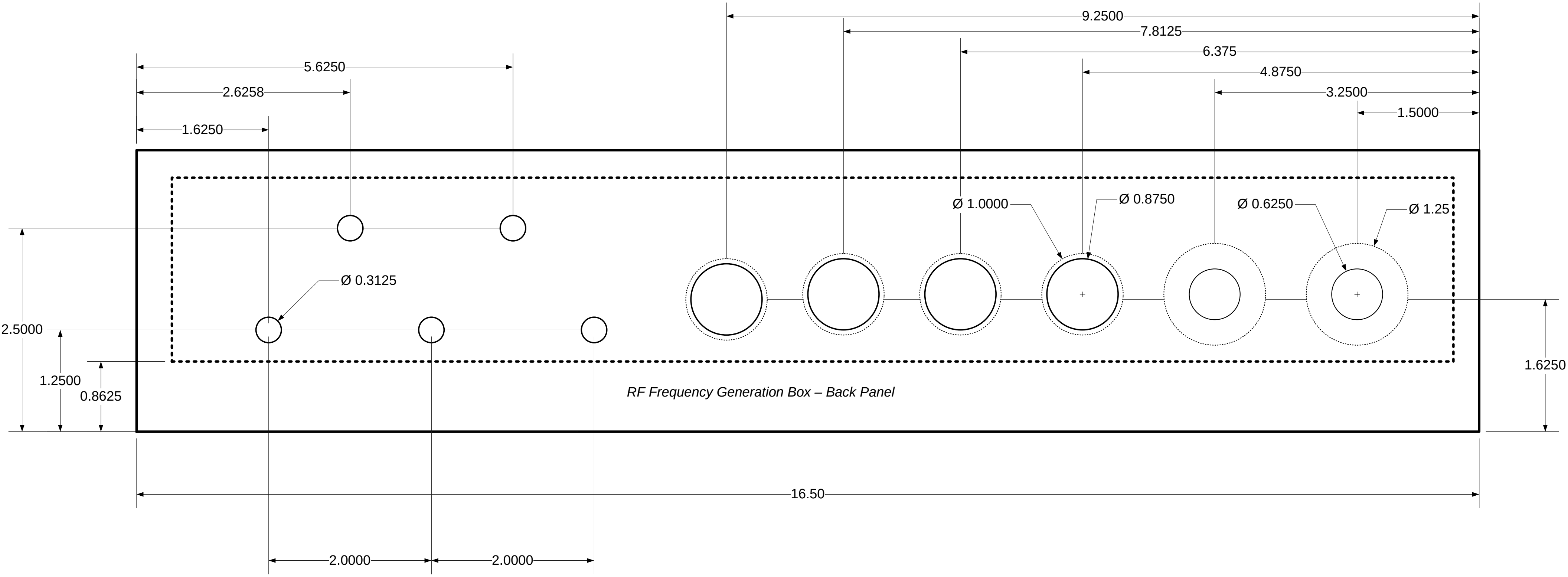
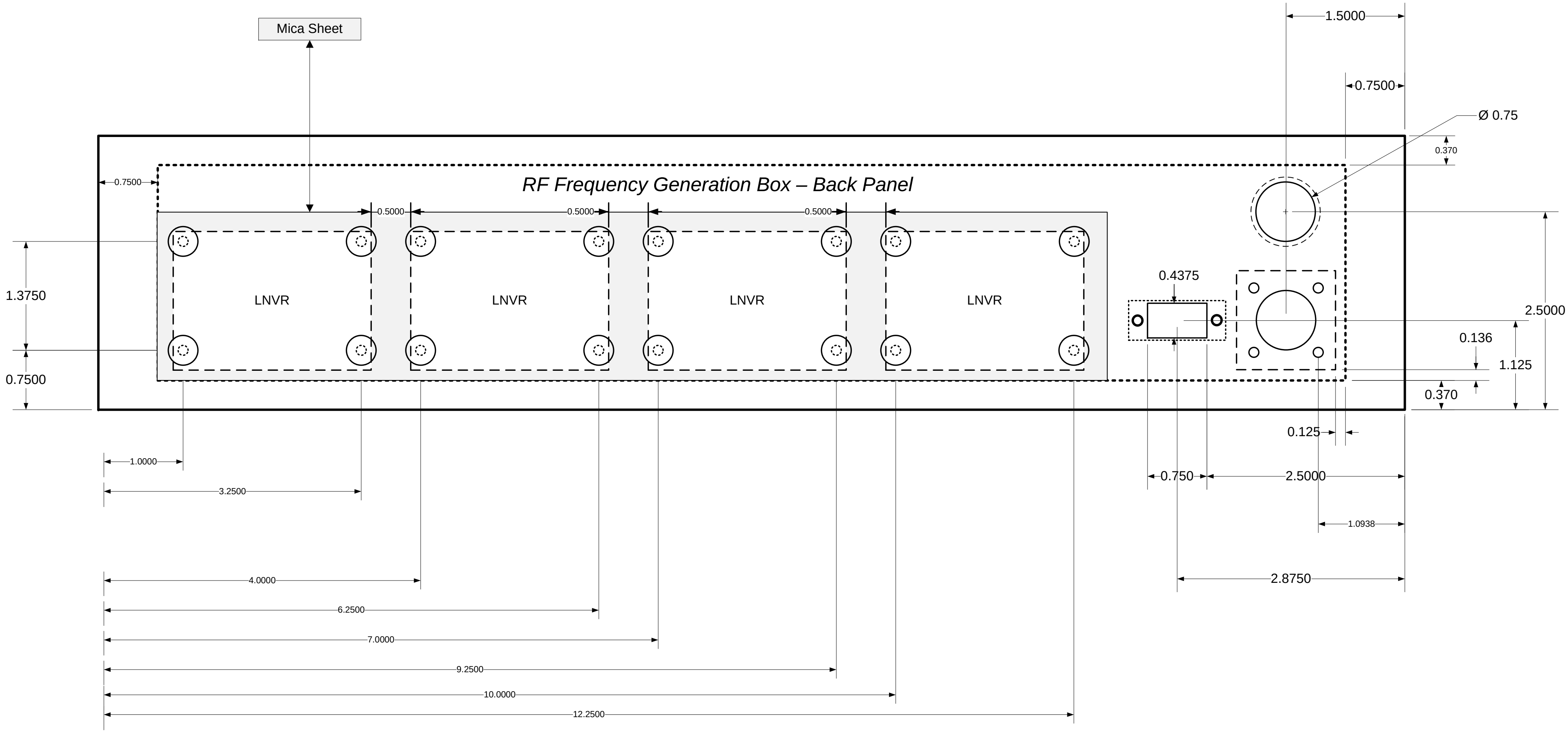
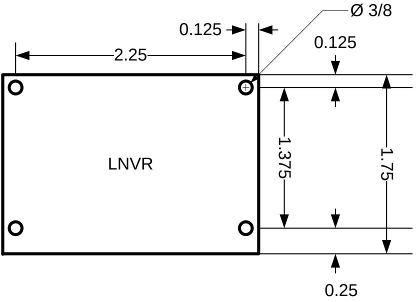


Figure 18: This plot shows how the locking point can depend on the amplitude of a line at 22 MHz ($2f_2$.

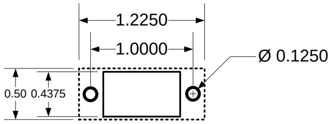
C Drawings


RF Frequency Generation Box – Back Panel

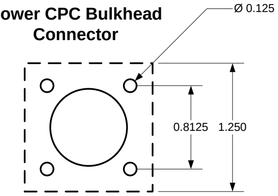


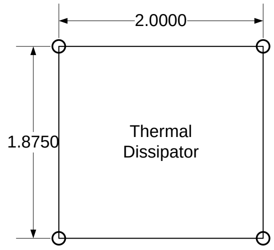


Voltage Cont'd Att. (VCA)



Power CPC Bulkhead Connector





D Data Sheets

04609 REV	DATE	REVISION RECORD	DWN	AUTH
-	01-07-10	Draft	PAC	

OUTPUT

Frequency

11.065 MHz

Level

+13 ±2 dBm into 50 ohms

STABILITY

Aging

5×10^{-10} per day

after 30 days operating, typical

Phase Noise L(f)

10 Hz	-120 dBc/Hz
100 Hz	-150 dBc/Hz
1 kHz	-165 dBc/Hz
10 kHz	-165 dBc/Hz

Temperature Stability

$\pm 5 \times 10^{-9}$, 0° to +50°C (Ref +25°C)

MECHANICAL

Dimensions

2 x 2 x 1”

Connectors

SMA(f) and feedthru capacitor

Packaging

Sealed steel can

POWER REQUIREMENTS

Warm-Up Power

≤ 5 Watts for 5 minutes

Total Power

≤ 2.2 Watts at +25°C

Supply Voltage

+15 VDC ±5%

ADJUSTMENT

Mechanical Tuning

$\pm 1 \times 10^{-6}$

Electrical Tuning

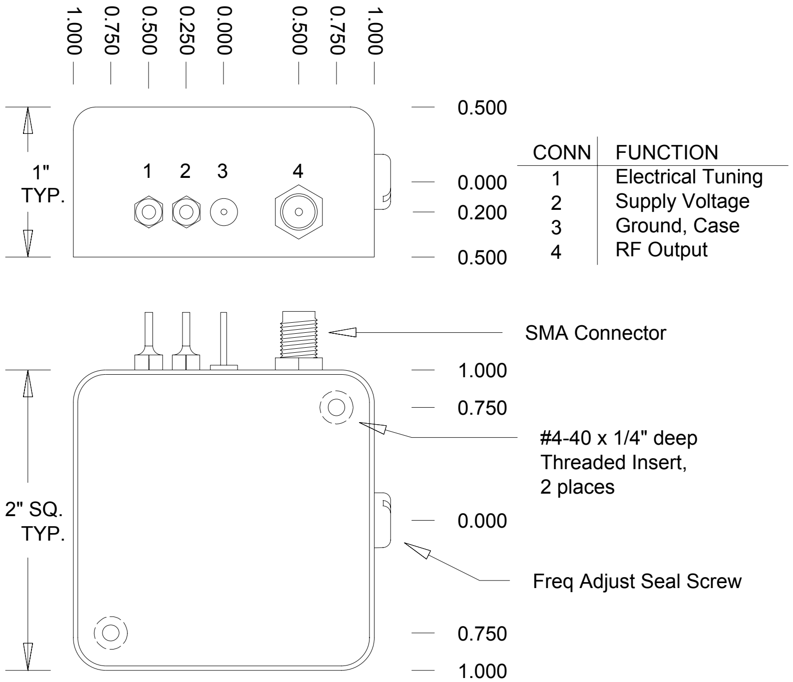
$\pm 2 \times 10^{-7}$, ±5 VDC

Negative slope

CRYSTAL

Type

11.065 MHz SC-cut



CONN	FUNCTION
1	Electrical Tuning
2	Supply Voltage
3	Ground, Case
4	RF Output

Connector numbers are for reference only, they are not marked on unit.

Wenzel Associates, Inc.
Austin, Texas

Title:
11.065 MHz-SC Streamline Crystal Oscillator

P/N:	Rev:	Date:	Drawn:	Ref:
500-21907	**-**	**01-07-10**		

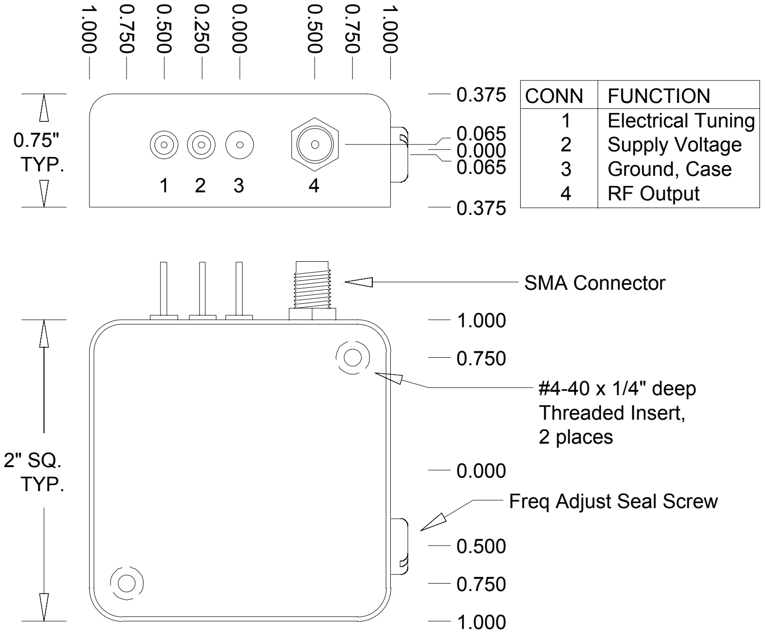
Tolerances: (except as noted) Dimensions are in inches	0.XX Dec:	0.XXX Dec:	FSCM:	
	±0.030”	±0.010”	62821	Page 1 of 1

REV	DATE	REVISION RECORD	DWN	AUTH
-	01-07-10	Draft	PAC	

OUTPUT
Frequency
29.485 MHz
Level
+13 dBm ±2dB into 50 ohms
STABILITY
Aging
1 x 10^{-6} per year
after 30 days operating, typical
Phase Noise L(f)

100 Hz	-130 dBc/Hz
1 kHz	-150 dBc/Hz
10 kHz	-165 dBc/Hz
20 kHz	-165 dBc/Hz

Temperature Stability
±5 x 10^{-7}, 0° to +50°C (Ref +25°C)
MECHANICAL
Dimensions
2 x 2 x 0.75”
Connectors
SMA(f) and feedthru capacitor
Packaging
Sealed steel can
POWER REQUIREMENTS
Warm-Up Power
≤ 5 Watts for 5 minutes
Total Power
≤ 2.7 Watts at +25°C
Supply Voltage
+15 VDC ±5%
ADJUSTMENT
Mechanical Tuning
±4 x 10^{-6}
Electrical Tuning
±5 x 10^{-7}, ±5 VDC
Negative slope
CRYSTAL
Type
29.485 MHz SC-cut



CONN	FUNCTION
1	Electrical Tuning
2	Supply Voltage
3	Ground, Case
4	RF Output

Connector numbers are for reference only, they are not marked on unit.

Wenzel Associates, Inc.
Austin, Texas

Title:
29.485 MHz-SC Sprinter Crystal Oscillator

P/N:	Rev:	Date:	Drawn:	Ref:
500-21908	-	01-07-10		

Tolerances: (except as noted) Dimensions are in inches	0.XX Dec:	0.XXX Dec:	FSCM:	
	±0.030”	±0.010”	62821	Page 1 of 1

REV	DATE	REVISION RECORD	DWN	AUTH
-	11-23-09	Draft	VG	JR

INPUT

Input Frequency

11.06 MHz

Input Power Level

+13 dBm, ±2 dBm

OUTPUT

Output Frequency

55.30 MHz

Output Power Level

+20 dBm, ±2 dBm

Harmonics

≤ -60 dBc

Sub-Harmonics

≤ -60 dBc

POWER

Input Voltage

+15 VDC, ±5%

Current

200 mA maximum

Phase Noise (Input Referred)

10 Hz	-110 dBc/Hz
100 Hz	-140 dBc/Hz
1 kHz	-160 dBc/Hz
10 kHz	-165 dBc/Hz

MECHANICAL

Dimensions

3 x 1.25 x 0.8”

Connectors

Feed-thru capacitor pin for power, ground terminal

Female SMA for input / output

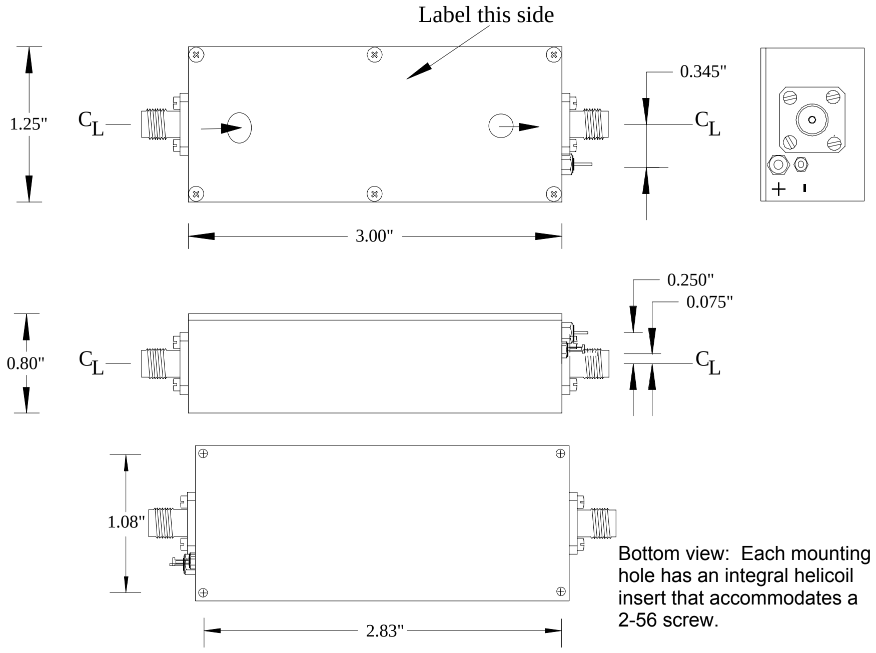
Packaging

Nickel-plated machined aluminum case

Label

Label as follows on conventional label and cover with lexan Blue Tops label:

600-21755
MULTIPLIER
+15 VDC
SN – Date Code



Bottom view: Each mounting hole has an integral helicoil insert that accommodates a 2-56 screw.

Ordering Information: LNOM - F - M - I - O - A1 - A2

Model
Input Frequency (MHz, 5 to 300)
Multiplication Factor (3,5,7,9,11)
Input Level (dBm, +10 to +15)
Output Level (dBm)
First Amplifier Option
Second Amplifier Option

X indicates no Amp

Connections

→○	RF In
○→	RF Out
+	+15 VDC Input
-	Case Ground

Wenzel Associates, Inc.
Austin, Texas

Title:
Blue Tops Low Noise Fixed Frequency Odd-Order Multiplier

P/N:	Rev:	Date:	Drawn:	Ref:
600-21755	-	11-23-09		

Tolerances: (except as noted) Dimensions are in inches	0.XX Dec:	0.XXX Dec:	FSCM:	
	±0.030”	±0.010”	62821	Page 1 of 1

REV	DATE	REVISION RECORD	DWN	AUTH
-	10-11-05	Draft	PAC	

ELECTRICAL

Input Voltage

Fixed between +8 VDC and +28 VDC, typical
(Other voltages may be acceptable – consult factory)

Output Voltages

Fixed between +5 VDC and +25 VDC, typical
(Other voltages may be acceptable – consult factory)

Output Current

Current will vary depending on voltage levels, differential and input voltage tolerance.
Example:
$I_{OUT} \leq 1$ amp under the following conditions:

- Input to Output Differential > 3 VDC
- Input Voltage Tolerance < 5%

MECHANICAL

Dimensions

1.750 x 2.5 x 1”

Packaging

Nickel-plated machined aluminum

Mounting

Two mounting options are available. The 2.5 x 1” surface will offer the best thermal dissipation.

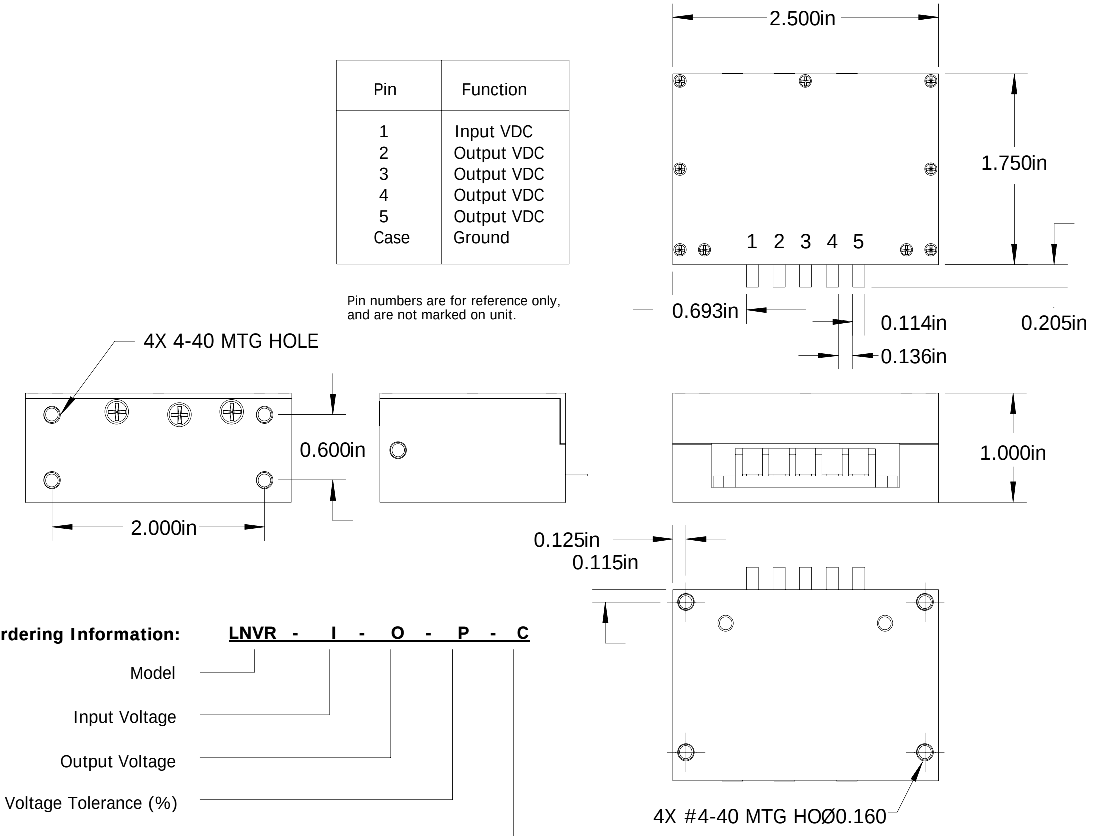
OTHER

Label

Label as follows on conventional label:
LNVR – I – O – P – C
Voltage Regulator
SN – Date Code
(Replace I, O, P and C with the actual values)

Pin	Function
1	Input VDC
2	Output VDC
3	Output VDC
4	Output VDC
5	Output VDC
Case	Ground

Pin numbers are for reference only, and are not marked on unit.



Ordering Information: LNVR - I - O - P - C

- Model
- Input Voltage
- Output Voltage
- Input Voltage Tolerance (%)
- Output Current

Wenzel Associates, Inc.
Austin, Texas

Title: **Low Noise Voltage Regulator**

P/N:	Rev:	Date:	Drawn:	Ref:
LNVR	-	10-11-05		

Tolerances: (except as noted) Dimensions are in inches	0.XX Dec:	0.XXX Dec:	FSCM:	
	±0.030”	±0.010”	62821	Page 1 of 1

Coaxial

Amplifier

ZFL-1HAD

50Ω High Isolation 10 to 500 MHz


ZFL-1HADX


ZFL-1HAD

CASE STYLE: SS98

Connectors	Model	Price	Qty.
SMA	ZFL-1HAD	$210.00 ea.	(1-9)
BRACKET	**(OPTION "B")**	$2.50	(1+)
SMA	ZFL-1HADX	$200.00 ea.	(1-9)

Features

- wideband, 10 to 500 MHz
- active directivity (isolation-gain), 30 dB typ.

Applications

- VHF/UHF
- laboratory use
- receivers
- two-tone, 3rd order IM testing

Amplifier Electrical Specifications

MODEL NO.	FREQUENCY (MHz)		GAIN (dB)		MAXIMUM POWER (dBm)			DYNAMIC RANGE		VSWR (:1) Typ.		ACTIVE DIRECTIVITY[1] (dB)				DC POWER	
				Flatness Max.	Output (1 dB Compr.)			NF (dB) Typ.	IP3 (dBm) Typ.			L_W		U		Volt (V) Nom.	Current (mA) Max.
	f_L	f_U	Min.	Total Range	L_W	U	Input (no damage)			In[2]	Out	Typ.	MIn.	Typ.	Min.		
ZFL-1HAD	10	500	10	±1.0	+20	+20	+17	7.5	+30	1.3	1.35	30	20	25	18	15	115
ZFL-1HADX*	10	500	10	±1.0	+20	+20	+17	7.5	+30	1.3	1.35	30	20	25	18	15	115

* Heat sink not included

L_W= low range (f_L to f_U/2)

U= upper range (f_U/2 to f_U)

[1] Active Directivity(dB)= Isolation (dB)- Gain (dB)

[2] Input VSWR in 10-20 MHz band increases to 1.45:1 at -20ºC.

Below 50 MHz, NF increases to 11dB typ. at 10 MHz

Open load is not recommended, potentially can cause damage.
With no load derate max input power by 20 dB

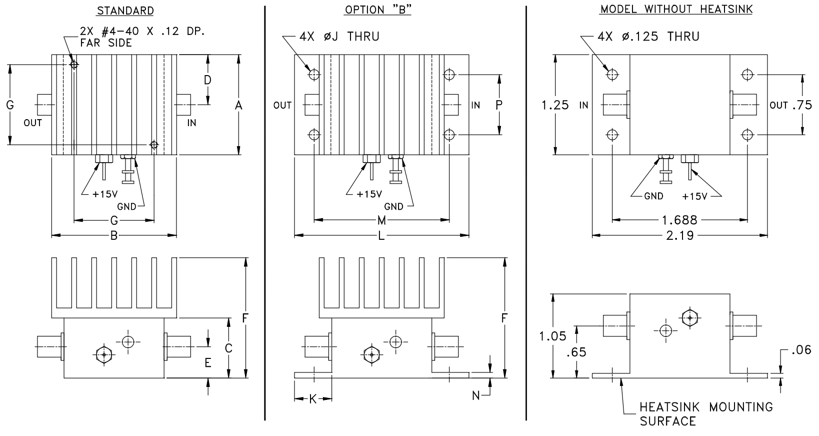
To order without heat sink, add suffix X to model number. Alternative heat sinking and heat removal must be provided by the user to limit maximum temperature to 71°C, in order to ensure proper performance. For reference, this requires thermal resistance of user's external heat sink to be 15°C/W Max.

Maximum Ratings

Operating Temperature	-20°C to 71°C
Storage Temperature	-55°C to 100°C
DC Voltage	+17V Max.

Permanent damage may occur if any of these limits are exceeded.

Outline Drawing



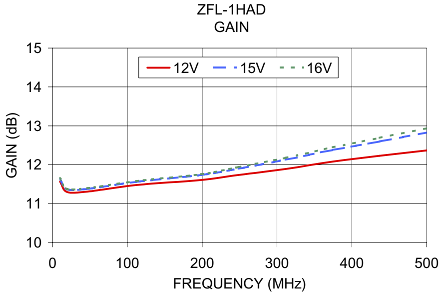
Outline Dimensions (inch / mm)

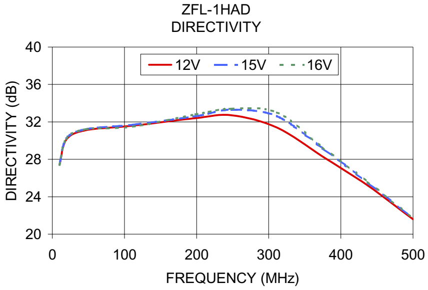
A	B	C	D	E	F	G	H	J	K	L	M	N	P	wt*
1.25	1.56	.75	.63	.39	1.50	1.000	--	.125	.46	2.19	1.688	.06	.750	grams
31.75	39.62	19.05	16.00	9.91	38.10	25.40	--	3.18	11.68	55.63	42.88	1.52	19.05	85.0

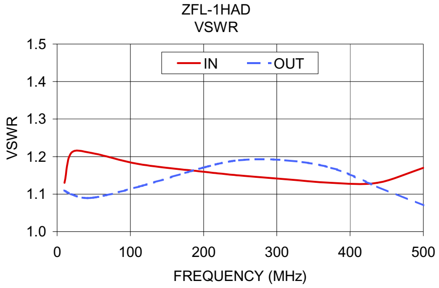
*70 grams with heat sink

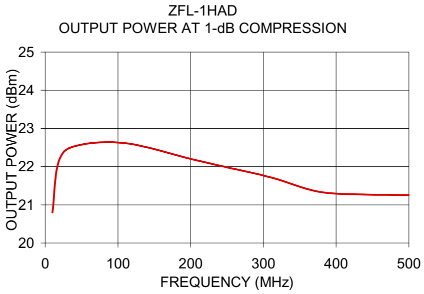
Typical Performance Data/Curves **ZFL-1HAD**

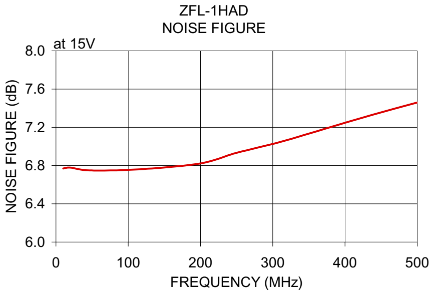
FREQUENCY (MHz)	GAIN (dB)			DIRECTIVITY (dB)			VSWR (:1)		NOISE FIGURE (dB)	POUT at 1 dB COMPR. (dBm)
	12V	15V	16V	12V	15V	16V	IN	OUT	15V	15V
10.00	11.57	11.63	11.65	27.40	27.50	27.40	1.13	1.11	6.77	20.80
19.30	11.30	11.37	11.38	30.10	30.20	30.20	1.21	1.10	6.78	22.17
46.50	11.31	11.38	11.40	31.10	31.20	31.20	1.21	1.09	6.75	22.56
111.80	11.48	11.56	11.58	31.60	31.70	31.50	1.18	1.12	6.76	22.61
198.50	11.61	11.74	11.76	32.40	32.60	32.80	1.16	1.17	6.82	22.21
248.70	11.74	11.90	11.94	32.70	33.30	33.40	1.15	1.19	6.93	21.99
311.50	11.89	12.13	12.18	31.40	32.60	33.00	1.14	1.19	7.05	21.71
374.40	12.08	12.38	12.45	28.30	29.20	29.30	1.13	1.17	7.19	21.35
437.20	12.23	12.60	12.69	25.20	25.50	25.60	1.13	1.12	7.33	21.27
500.00	12.37	12.83	12.94	21.60	21.70	21.70	1.17	1.07	7.46	21.26









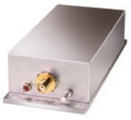


Coaxial

Amplifier

ZHL-2

50Ω Medium High Power 10 to 1000 MHz



ZHL-2X

ZHL-2

SMA version shown

Features

- wideband, 10 to 1000 MHz
- high IP3, +38 dBm typ.
- medium high power, 29 dBm min.

Applications

- VHF/UHF
- cellular
- instrumentation
- laboratory

CASE STYLE: T34

Connectors	Model	Price	Qty.
BNC	ZHL-2	$349.00 ea.	(1-9)
BNC	ZHL-2X	$339.00 ea.	(1-9)
SMA	ZHL-2-S	$359.00 ea.	(1-9)
SMA	ZHL-2X-S	$349.00 ea.	(1-9)
N-TYPE	ZHL-2-N	$359.00 ea.	(1-9)
N-TYPE	ZHL-2X-N	$349.00 ea.	(1-9)

Electrical Specifications

MODEL NO.	FREQ. (MHz)		GAIN (dB)		MAXIMUM POWER OUTPUT (dBm)		DYNAMIC RANGE		VSWR (:1) Max.		DC POWER	
	f_L	f_U	Min.	Flatness Max.	(1 dB Compr.) Min.	Input (no damage)	NF (dB) Typ.	IP3 (dBm) Typ.	In	Out	Volt (V) Nom.	Current (A) Max.
ZHL-2	10	1000	16	±1.0	+29	+15	9.0	+38	2.0	2.0	24	0.6
ZHL-2X*	10	1000	16	±1.0	+29	+15	9.0	+38	2.0	2.0	24	0.6

* Heat sink not included
Open load is not recommended, potentially can cause damage.
With no load derate max input power by 20 dB

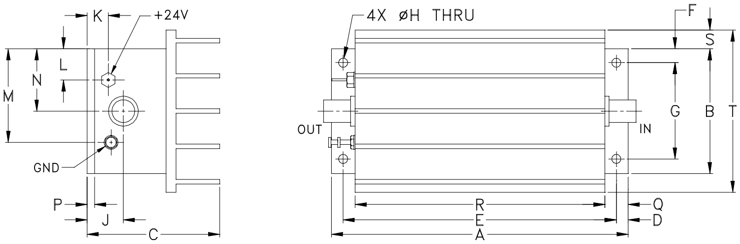
To order without heat sink, add suffix X to model number. Alternative heat sinking and heat removal must be provided by the user to limit maximum temperature to 65°C, in order to ensure proper performance. For reference, this requires thermal resistance of user's external heat sink to be 1.35°C/W Max.

Maximum Ratings

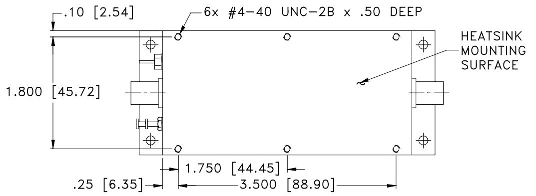
Operating Temperature	-20°C to 65°C
Storage Temperature	-55°C to 100°C
DC Voltage	+25V Max.

Permanent damage may occur if any of these limits are exceeded.

Outline Drawing



MOUNTING INFORMATION FOR MODELS WITHOUT HEATSINK



Outline Dimensions (inch / mm)

A	B	C	D	E	F	G	H	J	K	L	M	N	P	Q	R	S	T	wt
4.75	2.00	2.12	.19	4.375	.23	1.540	.144	.58	.34	.50	1.50	1.00	.12	.38	4.00	.30	2.60	grams*
120.65	50.80	53.85	4.83	111.13	5.84	39.12	3.66	14.73	8.64	12.70	38.10	25.40	3.05	9.65	101.60	7.62	66.04	440.0

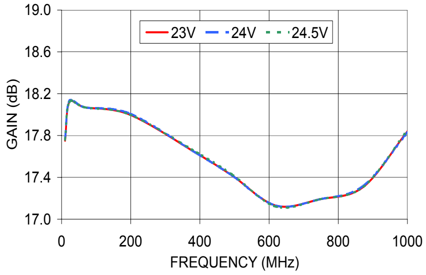
*325 grams without heatsink

Typical Performance Data/Curves

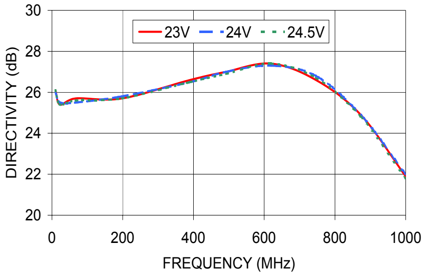
ZHL-2

FREQ. (MHz)	GAIN (dB)			DIRECTIVITY (dB)			VSWR (:1)		NOISE FIGURE (dB)	FREQ. (MHz)	POUT at 1 dB COMPR. (dBm)
	23V	24V	24.5V	23V	24V	24.5V	IN	OUT	24V		24V
10.00	17.75	17.77	17.76	26.10	26.00	26.10	1.58	1.87	9.19	10	30.03
22.60	18.12	18.13	18.12	25.40	25.50	25.40	1.08	1.80	8.56	100	30.09
66.80	18.07	18.07	18.07	25.70	25.50	25.60	1.11	1.76	7.95	200	30.23
197.60	18.00	18.01	18.00	25.70	25.80	25.70	1.23	1.59	8.11	300	30.46
390.80	17.63	17.63	17.64	26.60	26.50	26.50	1.43	1.22	8.46	400	30.69
492.30	17.42	17.42	17.43	27.00	27.00	26.90	1.54	1.09	8.54	500	31.05
619.20	17.13	17.13	17.12	27.40	27.30	27.40	1.65	1.20	8.58	600	31.37
746.20	17.19	17.19	17.19	26.60	26.80	26.70	1.71	1.20	8.69	700	31.44
873.10	17.31	17.32	17.31	24.90	24.90	24.80	1.70	1.15	9.06	800	31.67
1000.00	17.84	17.83	17.85	21.90	22.00	21.80	1.39	1.26	9.69	1000	31.41

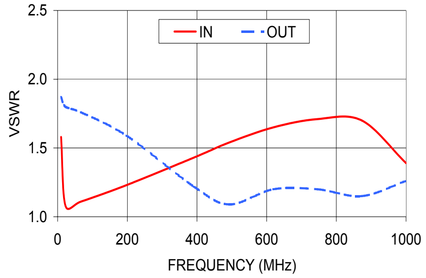
ZHL-2
GAIN



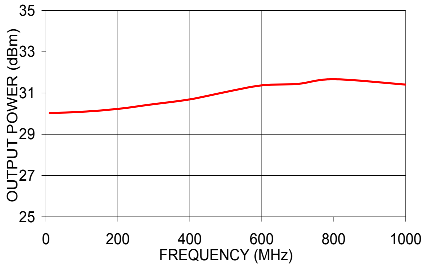
ZHL-2
DIRECTIVITY



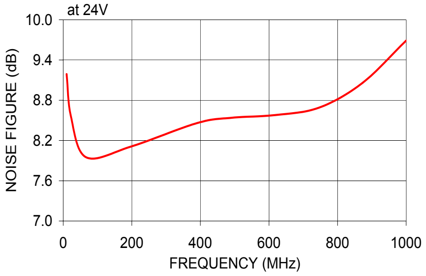
ZHL-2
VSWR



ZHL-2
OUTPUT POWER AT 1-dB COMPRESSION



ZHL-2
NOISE FIGURE



Models 3003, 3006, 3007, 3010, & 3014 dc to 2.5 GHz
Models 3053 & 3054 dc to 6.0 GHz
Manual Step Attenuators 1 Watt

Rugged SMA Connector

Features

- **New Models -** Models 3053 & 3054 offer an extended frequency range to 6 GHz.
- **Available *Express* Models:** 3003-100
  3010-100
  3053-100
  3054-100

  Other models may be available for Express delivery.
- **High Reliability -** Repeatability better than 0.1 dB over frequency range and life. Weinschel patented detent mechanism, tested to 1,000,000 operations at +75°C, operates dependably even down to -40°C.
- **Product Uniformity -** High volume fabrication techniques, including injection molding, stamping, broaching and thick film printing ensure a cost effective and uniform product.
- **Low Frequency Sensitivity -** Typically 0.1 to 0.2 dB up to 2.5 GHz.
- **Shock Resistant -** 100% spring contact system withstands mechanical and thermal shock and eliminates the need for epoxy or solder.
- **Wide Selection -** Wide choice of attenuation ranges and increments in standard stock models. Single and dual drum configurations available.
- **Knob Included -** Knobs for both single and dual drum models are included with every attenuator. Characters are screened on the face of the knob insert which is coated with a clear layer of epoxy for protection.

Special Configurations

Some modifications to the basic configuration of the 3000 Series can be made during manufacturing. Examples of these special configurations are shafts having special lengths and ends; clockwise shaft rotation; modified mounting arrangements; and provisions for add-on items such as concentric potentiometer and ganged switches.

Specifications

NOMINAL IMPEDANCE: 50 Ω

FREQUENCY RANGE: FREQUENCY RANGE:

Models 3006, 3014:	dc to 1.25 GHz
Models 3003, 3007, 3010:	dc to 2.5 GHz
Models 3053, 3054:	dc to 6.0 GHz

INCREMENTAL ATTENUATION RANGE/STEPS:

Model 3003:	0-70 dB in 10 dB steps
Model 3006:	0-100 dB in 10 dB steps
Model 3007:	0-10 dB in 1 dB steps
Model 3010:	0-70 dB in 1 dB steps
Model 3014:	0-110 dB in 1 dB steps
Model 3053:	0-10 dB in 1 dB steps
Model 3054:	0-70 dB in 1 dB steps

POWER COEFFICIENT: < 0.006 dB/dB/watt

TEMPERATURE COEFFICIENT: 0.0004 dB/dB/ °C

TEMPERATURE RANGE:

Operating:	-40°C to +65°C
Non-Operating:	-54°C to +85°C

POWER RATING: 1 watts **average** @ 25°C ambient temperature, derated linearly to 0 watts @ 65°C. 100 watts **peak** (5 µsec pulse width; 0.5 % duty cycle).

ATTENUATION ACCURACY:

Model	Accuracy
3003	± 0.3 dB or 1% up to 60 dB ± 2% to 70 dB
3006	± 0.3 dB or 1% up to 60 dB ± 2% to 100 dB
3007, 3053	± 0.3 dB
3010	± 0.3 dB up to 10 dB ± 0.3 dB or 1.5% to 60 dB ± 2 % to 70 dB
3014	± 0.3 dB up to 10 dB ± 0.3 dB or 1.5% to 60 dB ± 3% to 110 dB
3054	± 0.3 dB or 2% (dc to 3 GHz) ± 0.3 dB or 3.5% (3 to 6 GHz)

CONNECTOR: SMA female connector per MIL-STD-348 interface dimensions - mate nondestructively with MIL-C-39012 connector.

TELEDYNE COUGAR
A Teledyne Technologies Company

Attenuator
5 to 1000 MHz

Technical Data

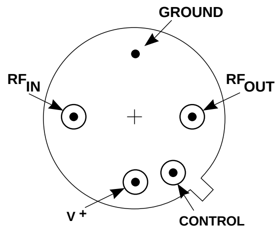
UTF-015

Features
- **< 1.6:1 VSWR**
- **20 dB of Attenuation**
- **Negative Control Voltage**

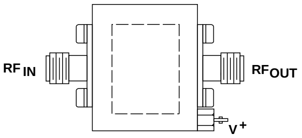
Applications
- **Open and Closed Loop Gain Control**
- **AGC Circuits**

Description
The UTF-015 is a thin-film voltage-controlled RF attenuator that offers a continuously-variable attenuation of up to 20 dB from 5 to 1000 MHz. Utilizing PIN diodes, attenuation over frequency is typically ±0.5 dB flat over the complete control voltage range. On the average, the attenuation will change roughly 5 dB per 2-volt increment. The UTF-015 is available in either the TO-8 hermetic case or connectorized TC-1 package.

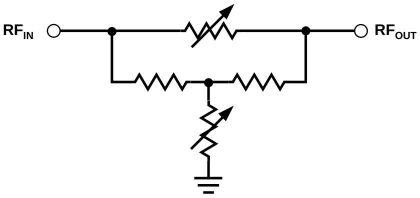
Pin Configuration
TO-8F



TC-1



Schematic



Maximum Ratings

Parameter	Maximum
DC Voltage	+17/–15 Volts
Continuous RF Input Power	+23.0 dBm
Operating Case Temperature	–55 to +125°C
Storage Temperature	–62 to +150°C
"R" Series Burn-In Temperature	+125°C

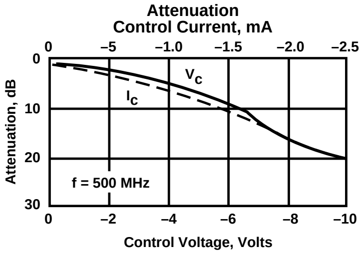
Weight: (typical) 2.1 grams

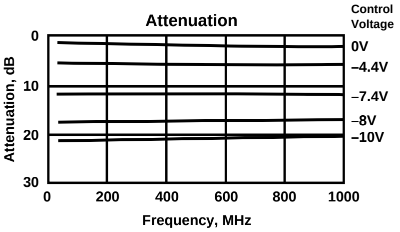
Electrical Specifications

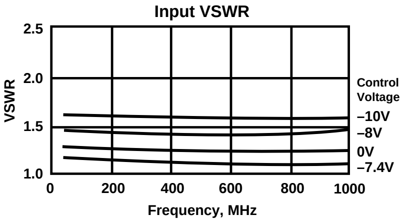
(Measured in 50 Ω system @ +15 VDC nominal unless otherwise noted)

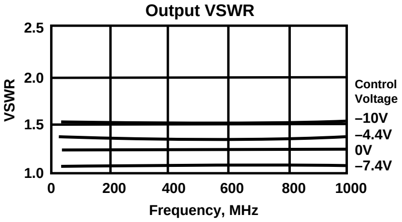
Symbol	Characteristic	Typical	Guaranteed Specifications		Unit
		T_C = 25°C	T_C = 0 to 50°C	T_C = –55 to +85°C	
BW	Frequency Range	5-1000	5-1000	5-1000	MHz
—	Attenuation, Min. (V_C = –10 V)	20.0	15.0	—	dB
—	Insertion Loss, Max. (V_C = 0 V)				
	5-500 MHz	1.5	2.0	—	dB
	500-1000 MHz	2.0	2.5	—	dB
—	VSWR (Worst Case In Attenuation Range)	1.5:1	2.0:1	—	—
—	Flatness Over Frequency	±.5	—	—	dB
—	Switching Speed (10% to 90%)	.5	—	—	ms
—	Bias Current	7	—	—	mA
—	Control Voltage	0 to –10	0 to –10	—	VDC
—	Control Current	0 to 7	—	—	mA

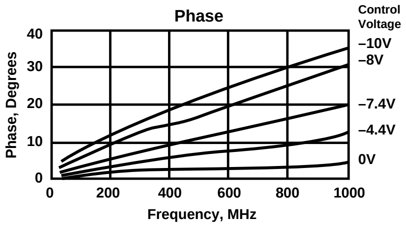
Typical Performance At 25°C

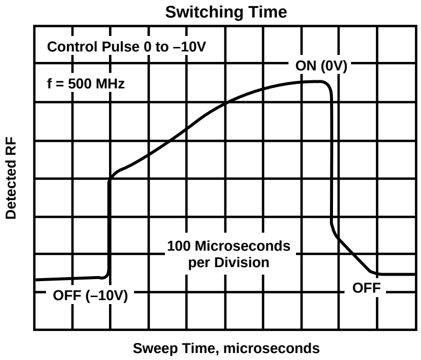




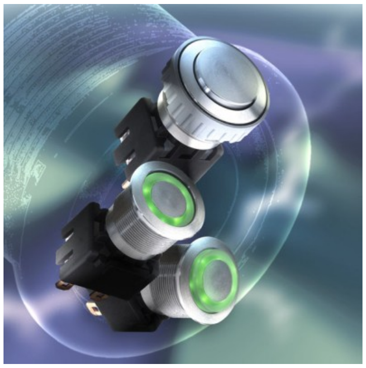








1 PRODUCT DESCRIPTION



Both, the housing and the actuator of the vandal-proof latching action switch MSM LA are made of high-quality stainless steel. By applying this robust and weather-resistant material, the switch is particularly suitable for the use in harsh environments. The MSM LA is available with mounting diameters of ∅ 19 and 22 mm.

Different types of contact cover a range of permissible switching voltages from 30 VDC to 250 VAC, switching currents are permissible from 0.1 to 12 Ampere. The MSM is equipped with quick connect terminals to permit fast connection. The cables are plugged onto the switch assembly which is subsequently plugged onto the previously screwed-in housing assembly. Ring-illuminated versions are available for applications at night or as an optical status display. For all types, the MSM LA is available as a double-pole version.

2 TECHNICAL DATA AND DIMENSIONAL DRAWINGS

2.1 Technical Data

Electrical Data		
Switching Voltage min.	[V_{DC}]	30
Switching Voltage max.	[V_{AC}]	250
Switching Current min.	[A_{DC}]	0.1
Switching Current max.	[A_{AC}]	12
Rated Braking Capacity	[W]	3000
Lifetime (at 8A / 250 VAC)	[Actuations]	50,000
Initial Contact Resistance (at 12V / 1 ADC)	[mΩ]	< 100
Insulation Resistance (500 VDC)	[MΩ]	> 100

Mechanical Data		
Actuating Force typ.	[N]	10
Actuating Travel typ.	[mm]	4.5
Lifetime mechanical	[Actuations]	150,000
Contact Gap	[mm]	> 3

Starting Torque		MSM 19 LA	MSM 22 LA
Plastic Nut max.	[Nm]	4.5	3.5
Stainless Steel Nut* max.	[Nm]	12	16

* on request

Climatical Data		
Operating Temperature	[°C]	-40 bis +85
Storage Temperature	[°C]	-40 bis +85
Degree of Protection (DIN EN 60529)	[IP]	IP 67 Frontside IP 00 Rear Side

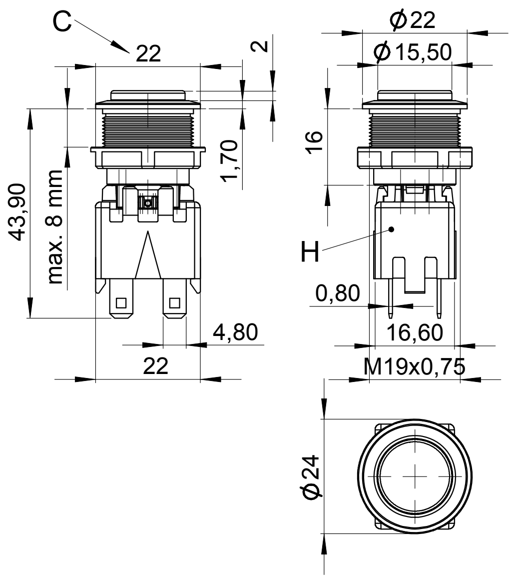
Ring Illumination		(MSM 19 LA RI and MSM 22 LA RI)
Supply Voltage U_{LED}	[V_{DC}]	24

Material	
Component	**Material with flammability rating**
Switcher Collet	PA66 Blend (UL94-V0 related to d ≥ 1,6mm)
Intermediate Connector	PA66 Blend (UL94-V0 related to d ≥ 1,6mm)
Contact Pin Adapter	PA66 Blend (UL94-V0 related to d ≥ 1,6mm)
Component	**Material without flammability rating**
Housing	Stainless Steel 1.4305
Actuator	Stainless Steel 1.4305
Illuminated Ring Actuator (Ring Illumination)	PC
Gasket	NBR70

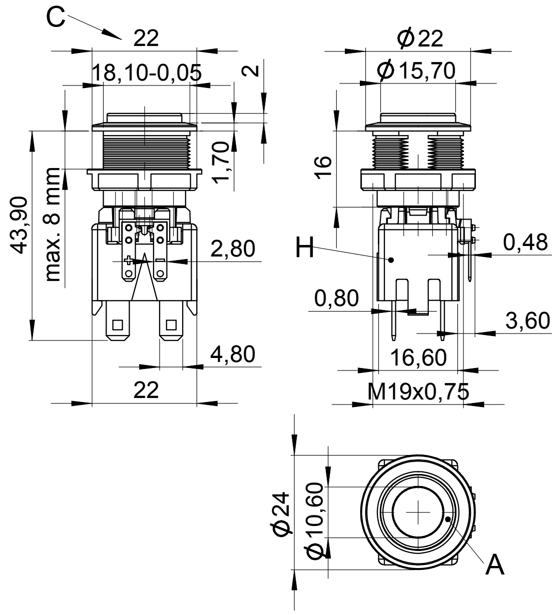
2.2 Component Dimensions

2.2.1 Component Dimensions M19

MSM 19 LA ST



MSM 19 LA RI

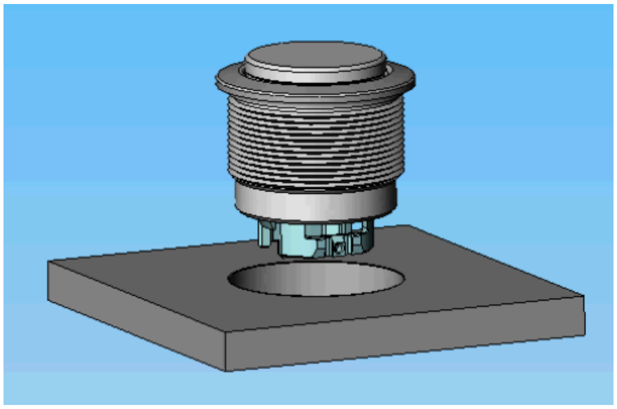


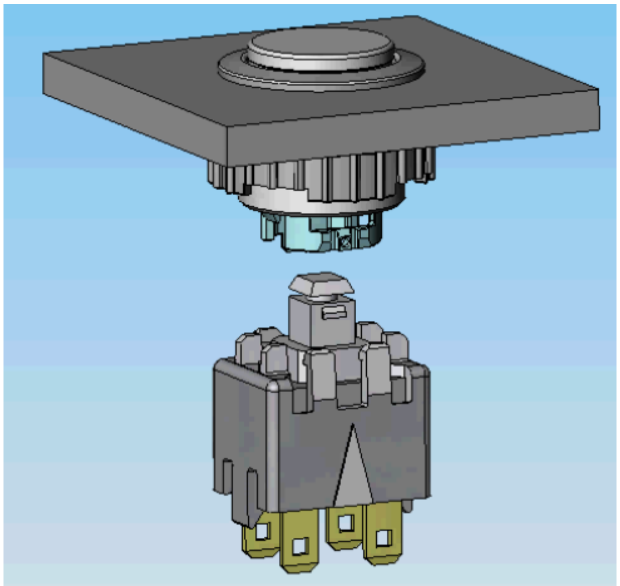
Legend

- *A = Illumination Area*
- *C = Width Across Flats*
- *D = Knurled Nut*
- *H = Switching Element*

5 Assembling

Actuating Element with the sealing ring is mounted to the frontpanel. Afterwards the switching element will be clipped on the actuating element as described by following pictures.





6 QUALIFICATION TEST

6.1 IP Protection Class

IP Protection Class IEC/DIN/EN/60529	IP 67

6.2 IK Protection Class

Tested Centrically

IK Protection Class DIN EN 50102	IK07

6.3 ESD Protection

ESD-Test according to DIN 61000-4-2:

4kV Contact Discharge	MSM LA ST	Ø 19; 22 mm

References

[1] Yun Chase. *Introduction to Choosing MLC Capacitors For Bypass/Decoupling Applications.* AVX Corporation.

[2] ISC Group. Advanced ligo length sensing and control final designadvanced ligo length sensing and control final design. Technical Report LIGO T1000298, LIGO, 2010.

[3] Kiwamu Izumi. *Triple Resonant EOM.* LIGO 40m, `http://lhocds.ligo-wa.caltech.edu:8000/40m/Upgrade_09/Multi_Resonant_EOM`. 40m Wiki.

[4] Kiwamu Izumi. Development of triple resonant eom for advanced detectors. Technical Report LIGO-G1000297, Caltech, LIGO 40m, 2010.

[5] Caryn Palatachi. Temperature sensors for the 40m interferometer. Technical Report T0900287, Caltech LIGO 40m, 2009.

[6] Richard Mask Walter Jung. *Picking Capacitors, Vol I, II*, audio edition, 1980.