# apolLO-32 Microwave LO

## Background, Theory of Operation and Test Instructions



## BACKGROUND

Knowing what frequency you are on has been the goal of many microwave operators. It makes finding other operators easier. On higher frequencies with weak signals, getting the antenna pointed in the right direction can be an issue and when combined with frequency uncertainty can make the search from someone even more difficult. On digital modes stability is not as much a preference or convenience as it is a necessity. We have all made contacts without the desired stability, but having the stability opens up new doors. apolLO-32 is a derivative of the initial apolLO I board. The apolLO I board is a USB programmable LO (program and forget) that also has the capability to host an on-board TCXO. apolLO-32 is a simplification of the design the does not support on on-board TCXO (an external reference is required) and all programming is done on one of 32 channels via jumpers or switches.

## FEATURES

- Pre-programmed for 32 commonly-used microwave L-band LO frequencies
- Dynamic optimization for temperature changes (automatically retunes PLL in the event of loss of lock)
- Requires and locks to external 10 MHz reference
- Low power, consuming less than 2W
- Exact size and connection replacement to DEMI MICROLO
- Connections for external lock indicator
- Excellent phase noise characteristics (-72dBc/Hz @ 100Hz, -82dBc/Hz @ 1kHz, -88dBc/Hz @ 10kHz)
- Superior stability limited only by quality of external reference which can be shared among several apolLO boards

## THEORY OF OPERATION

ApolLO is a frequency synthesizer designed to operate in the 1.0—1.2GHz range for use as a local oscillator (LO). Whereas the apolLO I's frequency is programmable via PC software and a USB port, apolLO-32 is programmed via a set of solder jumpers or switches. The PCB consists of four main sections. The power supply (section #1 in Figure 1) produces supply voltages required by the board.

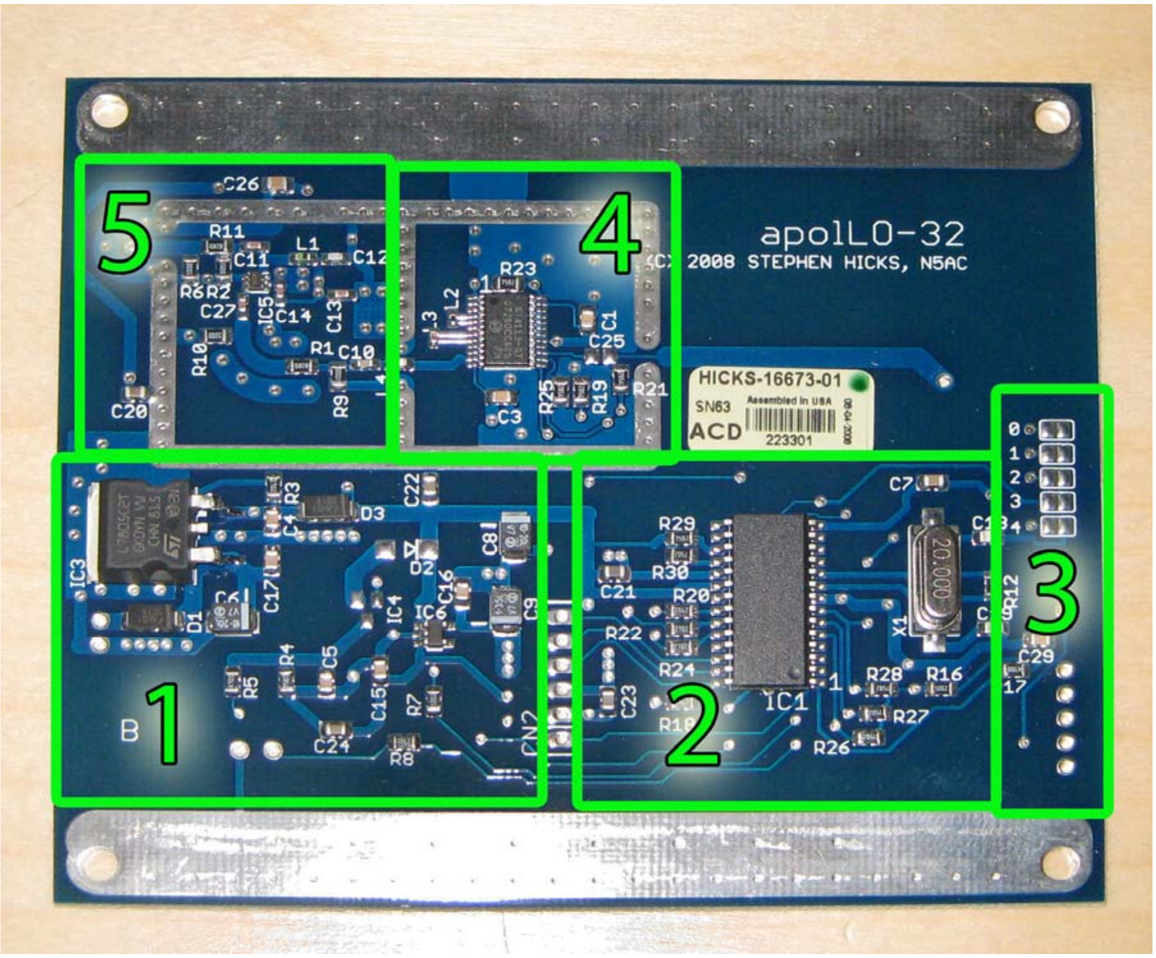


*Figure 1, PCB Sections*

The board will actually run off of up to 20V if necessary (more if higher voltage caps are used on the input of the voltage regulator – up to 35V).

The power supply produces two supply voltages, 4.5-5.0V used for the microprocessor and RF amplifier and 3.3V used for the synthesizer. Both supplies may also be used to power a TCXO.

The second major section of the board is the microprocessor (µP) (section #2 in Figure 1). The microprocessor's main purpose is to read jumpers and switches to determine which frequency the LO should use and to program the synthesizer with this information.

The PIC 18F2550 was chosen because of its ability to interface directly to USB without other components and because of its low cost, but the USB port is not used on the apolLO-32 design.  The µP uses a 20MHz clock which is used to derive the internal clock for the µP (48MHz).

On power-up, the microprocessor reads the jumper and switch settings (see section #3 in ***Figure 1***) and uses the index (one of 32) to look up the operating parameters from the on-board EEPROM and writes this to the synthesizer.  The synthesizer has no non-volatile memory for configurations itself.

The synthesizer needs a reference oscillator in order to function.  For the apolLO-32, an external 10MHz reference is required.  The apolLO I can use different frequency references and the PC software accommodates the different frequencies. The apolLO-32 has been programmed with 32 specific frequencies based on a 10MHz reference and therefore can only use a 10MHz reference.   From this reference, the synthesizer produces the programmed output frequency.  Internally, the synthesizer has a phase locked loop and the divider parameters for the loop can be programmed in the part after power-up.  A block diagram of the Si4133 is shown in ***Figure 2*** (the apolLO board actually uses the Si4113 part which does not include the IF synthesizer shown in the figure).  The ÷R and ÷N parameters change based on the desired output frequency, phase detector update rate and the reference provided to the synthesizer.  It is not necessary to understand how the synthesizer functions in detail to use the apolLO board, but many will find it interesting and will enjoy experimenting with the board to better understand how it operates.

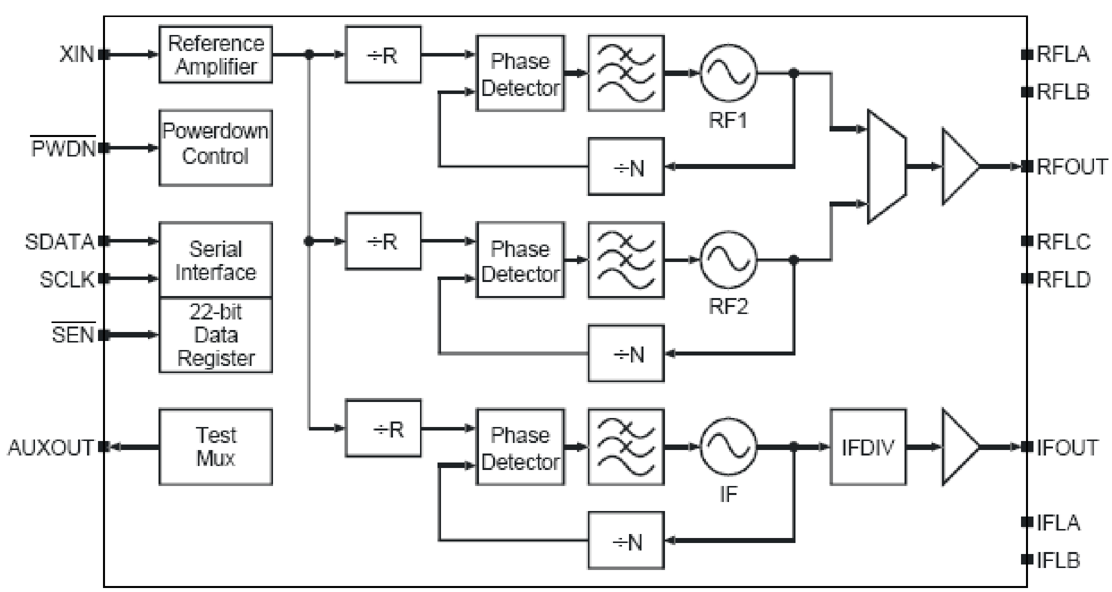



*Figure 2, Si4133 Block Diagram*

## REFERENCE SELECTION

The reference input is provided with the large number of surplus high-stability 10 MHz references in mind. Because the N and R dividers are pre-programmed directly from the µP with a 10MHz reference in mind, only a 10 MHz reference can be used on the apolLO-32. If you would like to use a different frequency reference (2-26MHz), the apolLO I can accommodate other reference frequencies.

The synthesizer (section #4 in ***Figure 1***) uses two external inductances to set the operating range of the two internal RF synthesizers. For this design, the objective was to fashion a PCB that would cover 902.1 – 1296.1MHz. This range encompasses the required starting LO frequencies for each of the DEMI transverter designs as can be seen in the table below as well as a number of weak signal frequencies and frequencies required for other transverters:

| Band | $F_{MICROLO}$ | Multiplier | $F_{LO}$ |
|---|---|---|---|
| 2304 MHz | 1080 MHz | 2 | 2160 MHz |
| 3456 MHz | 1104 MHz | 3 | 3312 MHz |
| 5760 MHz | 1123.2 MHz | 5 | 5616 MHz |
| 10368 MHz | 1136 MHz | 9 | 10224 MHz |

Finally, the RF output of the Si41xx synthesizer can vary from -8dBm to +1dBm. Since most LO chains or mixers require a higher output level, an integrated RF amplifier is included on the board (section #5 in ***Figure 1***). The ABA-54563 is a 20dB gain block with a P1dB of 16dBm. Sufficient padding is provided to isolate the synthesizer from the PA and the PA from the outside world (transverter). The output of the board has been pre-adjusted to +5dBm ±2dB.

The board is designed to be a form-fit replacement for the MICROLO. The top of the board is mounted to the inside of the case of a DEMI transverter with the two large ground areas coming in contact with the top of the transverter. All voltage in, RF out and reference-in are designed to be accessed from the rear of the board. The connections for RF out and voltage in are located in approximately the same position as they are on the MICROLO and the reference input is located near what is the rear of the transverter. It is expected that most will use the apolLO with an external reference connected to a BNC placed on the rear of the transverter – often an extra hole is already available where the split IF port would go. If you are using common IF in a DEMI transverter, this extra hole will be open.

## PROGRAMMING YOUR apolLO 32

The apolLO-32 can be "programmed" using either solder jumpers, switches or both. In general, solder jumpers on the board shown as section #3 in ***Figure 1*** are used to program the frequency as shown in JUMPER SETTINGS. Once the jumper is soldered, the LO will always start on the programmed frequency.

There is also a set of holes in the board that parallel the jumpers. In other words, they perform the same function as the jumpers. These can be used to dynamically change the LO frequency. There are a couple of reasons for doing this. First, if you operate in different band-segments, the LO can switch between segments so that a separate transverter or tuning of the IF to the new band segment is not required. Jumper positions were selected to make this an easy process also. Let's look at an example:

Suppose you used your transverter for both 3456.1 operation for terrestrial 3GHz, but also on 3400 MHz for EME. In the past, a separate LO or even transverter was required to accomplish the change of sub-band. With the apolLO-32, the same can be accomplished with a toggle switch.

By referencing the strap position chart, you can see that for 3456, straps 1 & 2 should be shorted. For 3400, straps 1, 2 & 3 should be shorted. So to enable the ability to switch frequencies, straps 1 & 2 should be soldered and a switch to ground should be installed in hole #3. The switch is then used to alternate between the configurations.

## UNDERSTANDING THE SYNTHESIZER AND LOCK

The apolLO-32 is preprogrammed to lock on to each of the 32 frequencies selectable. Situations could occur that would cause a loss-of-lock, however. The included LED should be placed on the front panel of the transverter and wired to the LOCK LED holes in the PCB (one hole is actually ground and this side of the LED could be connected to ground directly instead of the PCB hold if preferred). This LED can be used as a diagnostic aid to determine if any lock problems occur. The LED indication is derived from the LDETB output of the on-board synthesizer. Under normal conditions, the blue LED will light solid indicating a good lock. If, however, you are on the edge of the synthesizer range or there is another problem, the synthesizer may not be able to lock. Unfortunately, this is not always a "black and white" situation. Sometimes, the synthesizer will gradually lose lock. In this situation, the Blue LED would normally begin to very slowly dim in intensity as the lock weakened. Because we felt that this was an unacceptable way to report a lock failure (we can't seem to make our eyes detect a 1% loss of light in an LED), we have devised a better method for providing lock information. It works like this:

The apolLO microprocessor samples the LDETB (lock detect) line of the synthesizer about 10,000 times a second. After 1000 samples, the software examines the number of times that a lock was detected. If there was a lock detect signal present in every sample (100%), then the lock detect LED is lit solid and the Setup Utility reports the message "LOCKED."

If, on the other hand, it detects a 0-10% failure of lock detect, "Weak Lock" is reported and the LED will blink fast. In this situation, we can guarantee that the resulting signal is not pure carrier. You do not want to run the synthesizer in this mode, but we have setup the board to give you an indication of the type of problem encountered for aid in setup and troubleshooting. When lock is lost, the PLL will be operating open loop until lock is reestablished and the resulting carrier will be wandering around. For a weak lock, this can result is significant phase noise or even choppy reception as the LO wanders around. Again, we recommend not using the LO in this situation.

The moment that the microprocessor detects a lock failure, it first tries to reestablish lock by forcing the synthesizer to implement its internal auto-tune software. This software attempts to compensate for inductor values on the part, temperature variations and the like to get the oscillator back on channel. If a temperature drift is the cause of the lock loss, initially the auto-tune algorithm in the synthesizer will be successful. This is designed to automatically compensate for changes in temperature of the LO and the like. If you are watching the LO when this happens, the software forces the lock LED to go dark for approximately 20ms which appears as a short off blink. We tested this software in the lab by rapidly cooling and heating the PCB and watching a series of retunes occur successfully. In the field, these retunes generally would only occur with large temperature swings (> 30º C) which might happen over a series of hours in a rover or on a tower.

If the lock detect is lost for 10%-90% of the time, a "poor lock" is reported. A spectrum plot of the carrier during an example period is shown in ***Figure 3*** for information—again you would not want to use the LO in this situation and with the pre-programmed values, the synthesizer should never end up in this position.

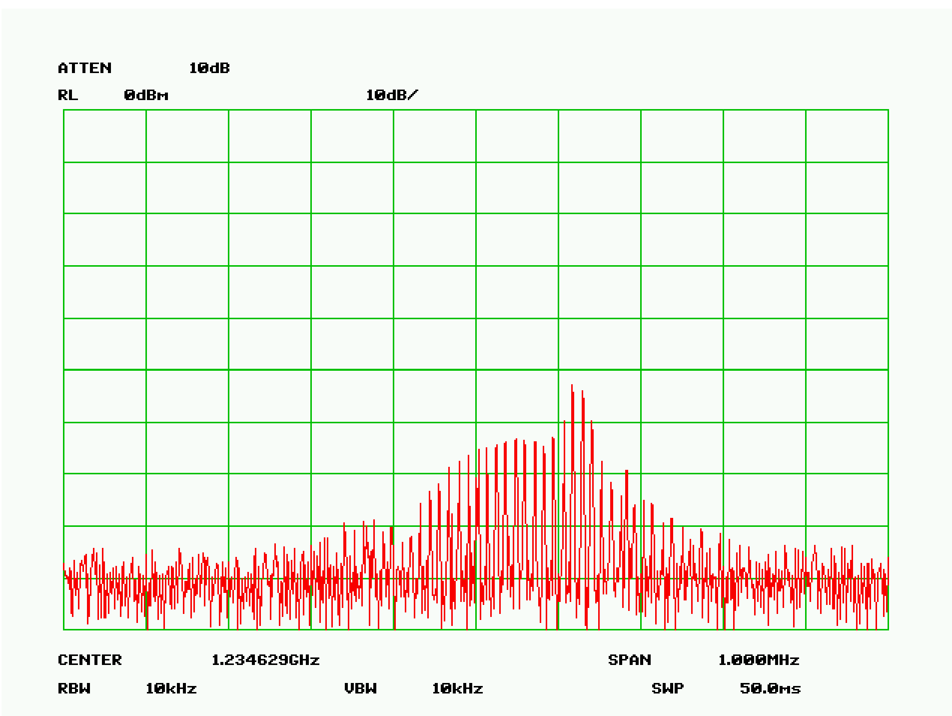



*Figure 3, Example Poor Lock Plot*

A lock detect percentage of <10% is reported as UNLOCKED and you would not want to use the LO in this situation either.

If you encounter a lock issues with the apolLO-32, there are a few things to try.  First, verify that your 10 MHz reference is successfully making it to the synthesizer board. Without the reference, there is nothing to lock to and you will always get a lock failure.

The next item to consider is a tuning issue. Although the software is designed to auto-retune in the event of a lock failure, it seems reasonable to reset the LO with a power cycle.  Again, this is not likely to solve the problem, but it is easy to test.
Lastly, the lock problem may be caused by a out-of-range error.  The VCO inside of the synthesizer chip has an adjustable range that is set by the external inductors on the part. These have been pre-selected to cover a broad range of frequencies (902-1296).  The range covered by the LO is, in fact, beyond the specifications of the synthesizer.  Because we were able to successfully obtain lock with a number of different parts outside of the normal range, the circuit was built around the chip's actual capabilities.

There are some caveats, however.  Both synthesizers in the Si4113 are employed to cover the range.  RF1 covers the low end of the range (903-1088) and RF2 covers the high-end (1103-1296).  The frequencies at either end of both of these ranges are on the edge of performance for the part.  Under temperature stresses, it is possible the synthesizer might have difficulty at one end of the other.  If you believe this is the failure mode you are in, the simplest solution is to slightly alter the position of the inductor in question responsible for the VCO tuning range.  The table below provides some suggestions:

In general, movement of about 1mm will move the center frequency of the VCO by 50MHz or so.  You may move the inductors a small amount to try to re-achieve lock if a particular frequency is giving you trouble.  Moving the inductor towards the synthesizer raises the frequency and moving it away from the synthesizer lowers the frequency.

## INSTALLING THE apolLO

Separate detailed instructions for installing the LO in a DEMI transverter are provided by DEMI.  Briefly, the steps are:

- ❒ If you have an existing MICROLO, remove it by unscrewing the four screws holding it to the transverter and unsolder the LO coax from the board and the power lead.

- ❒ The +9V line coming from the transverter control board should be soldered in the hole on the apolLO board marked +6-12V.  This should be done on the "back" of the PCB.  In actuality, the board can handle up to 20VDC.  Ground return is through the screws in the lid of the transverter and the coax although you can run a separate ground to the ground hole next to the +6-12V hole if you like.

- ❒ Connect the LO coax in the hole marked RF output on the apolLO. There is a circular ring around the hole for connecting the ground of the coax.

- ❒ Install the BNC in the rear panel in the available hole or drill a suitable hole and connect the reference input pad on the board to the BNC via a sall jumper of coax.

When transverter power is turned on the blue LED (locked) should be lit solid if the LO is programmed and locked on to the specified frequency.

If you would like to put an external lock LED on your transverter, two holes marked LOCK can be run out to an external LED. Depending on your LED selection, you may need to remove the existing LED on the board to ensure proper current/voltage makes it to your LED.

## PHASE NOISE CHARACTERISTICS

The apolLO-32's phase noise characteristics are a function of two key subsystems: the reference oscillator used by the synthesizer and the synthesizer itself. The apolLO has been tested with three references to date—a Z3801 GPS locked reference, an Isotemp OCXO (model 134) and the ECS 2.5ppm TCXO (on an apolLO I). From a phase noise perspective, the three of these are relatively similar in the results obtained.

***Figure 4*** shows a phase noise plot using the internal ECS 10MHz TCXO when the synthesizer is tuned to 1136 MHz. The readings from this plot are as follows:

| | |
|---|---|
| 10 Hz | -53 dBc/Hz |
| 100 Hz | -70 dBc/Hz |
| 1 kHz | -80 dBc/Hz |
| 10 kHz | -90 dBc/Hz |
| 100 kHz | -110 dBc/Hz |
| 1 MHz | -108 dBc/Hz |

The phase noise at 1 MHz is slightly higher due to the phase detector spurs at this frequency.

***Figure 5*** shows the same plot, but with an Isotemp OCXO model 134-10 at 10 MHz.

| | |
|---|---|
| 10 Hz | -65 dBc/Hz |
| 100 Hz | -75 dBc/Hz |
| 1 kHz | -82 dBc/Hz |
| 10 kHz | -90 dBc/Hz |
| 100 kHz | -110 dBc/Hz |
| 1 MHz | -112 dBc/Hz |

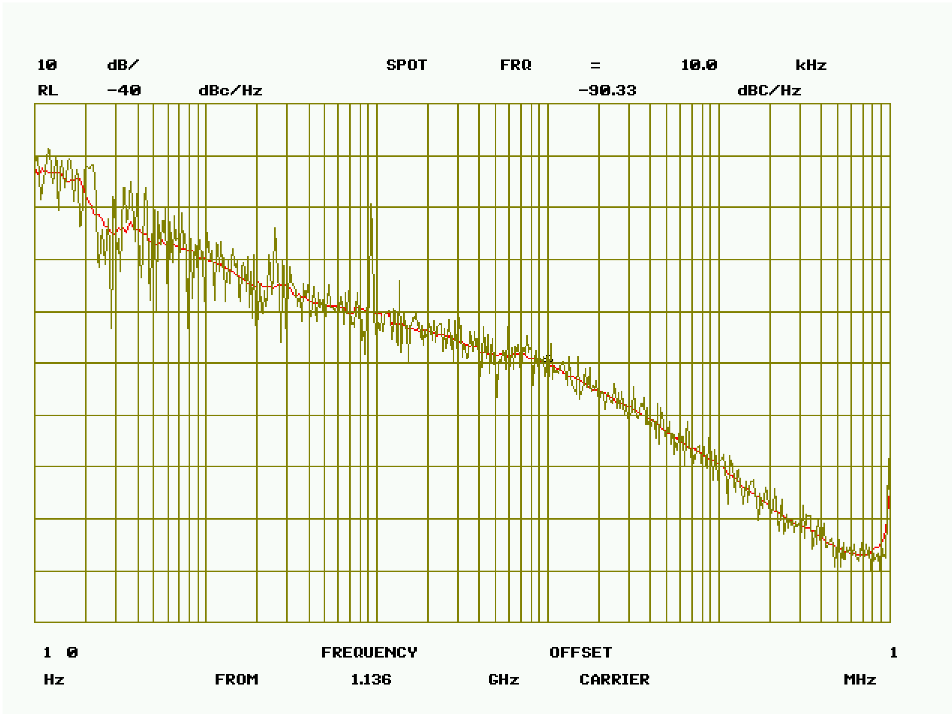



*Figure 4, ECS TCXO, 1136 MHz, 1MHz phase detector update*

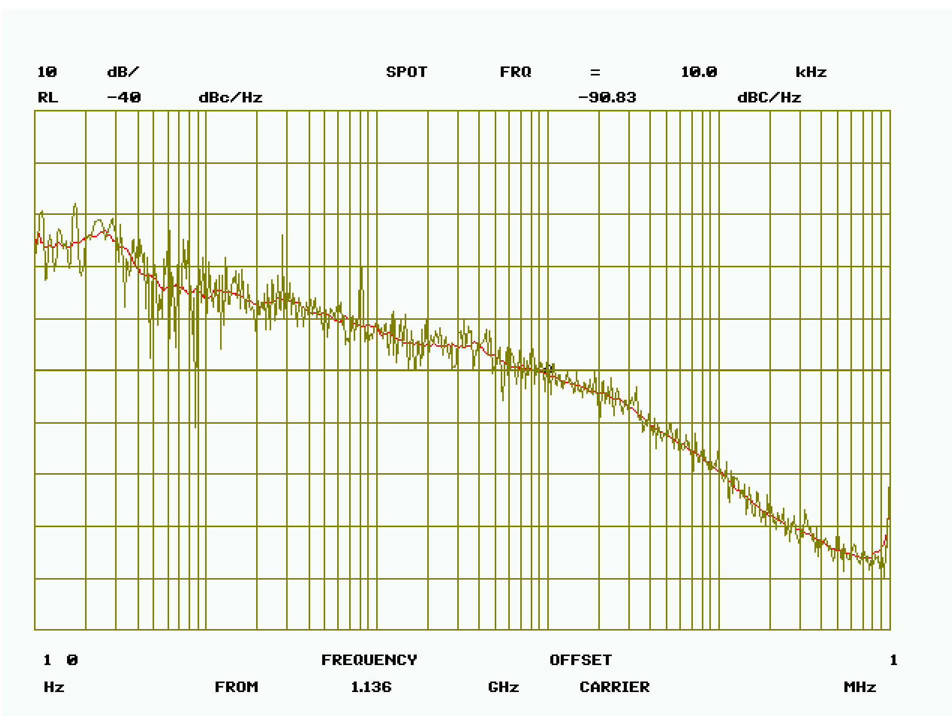



*Figure 5, Isotemp OCXO 134, 1136 MHz, 1MHz phase detector update*

The Isotemp OCXO has better phase noise close in (in the 10-100Hz range) than the ECS TCXO. If this oscillator is multiplied to 10224 MHz for use at 10 GHz, then the ECS would have a close in phase noise of approximately -35dBc/Hz whereas the Isotemp would be more in the -47dBc/Hz range.  This tends to say that the ECS would be fine at 10GHz, but that above this frequency, a reference with better phase noise should be used.

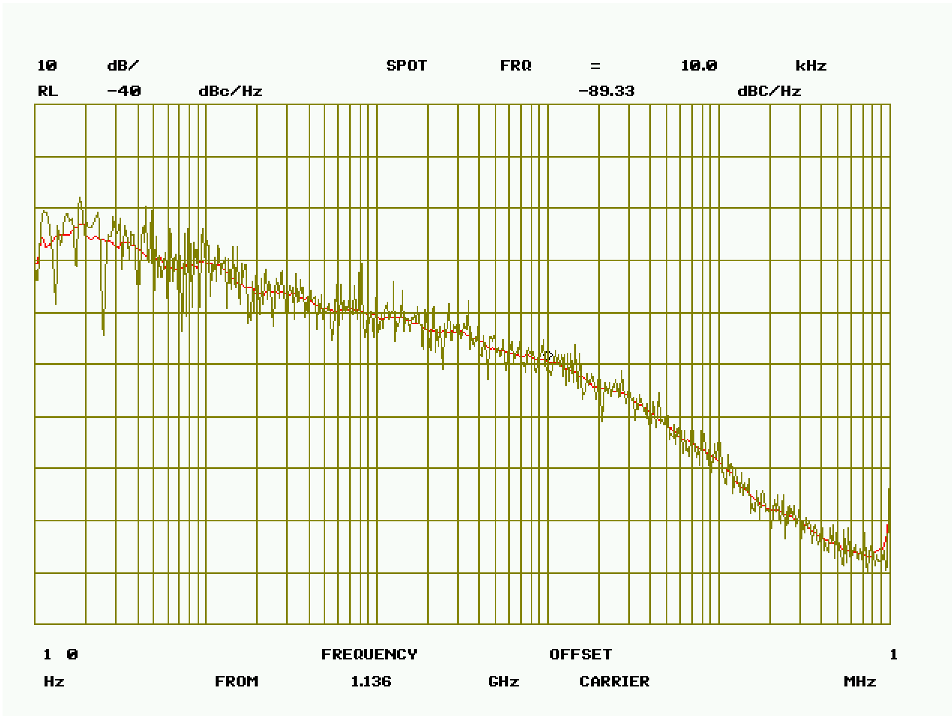



*Figure 6, apolLO with Z3801 10 MHz reference, 1136 MHz, 1MHz phase detector update*

The phase noise numbers using the Z3801 appear much better than the OCXO close in, but are a little misleading because the numbers actually peak to about -64dBc/Hz at 20Hz.  The numbers for the Z3801 are shown below.

| | |
|---|---|
| 10 Hz | -70 dBc/Hz |
| 100 Hz | -71 dBc/Hz |
| 1 kHz | -82 dBc/Hz |
| 10 kHz | -89 dBc/Hz |
| 100 kHz | -108 dBc/Hz |
| 1 MHz | -114 dBc/Hz |

Other than the design of the synthesizer, the other key component in phase noise is the update rate of the phase detector.  The higher the update rate, the less close-in phase noise is present.  For most amateur applications, it will be easy to use a 1 MHz phase update rate, but for some (5760 for example), a lower value will have to be used since the LO frequency is not on an even 1MHz boundary.

***Figure 7*** shows the same plot, but with a 100 kHz update rate.  As can be seen in the table that follows, the phase noise is significantly worse at lower offsets from the carrier, but better above 100kHz.  The supplied PC software attempts to maximize the phase detector update rate to as high a value as possible.  The synthesizer will not support a phase detector update rate above 1 MHz.

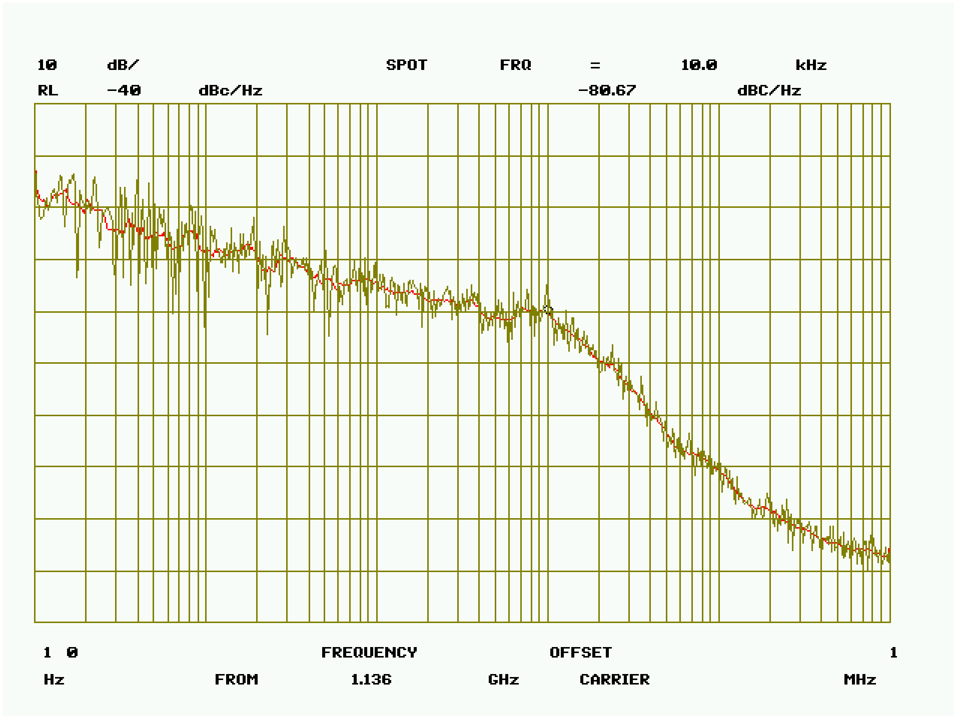
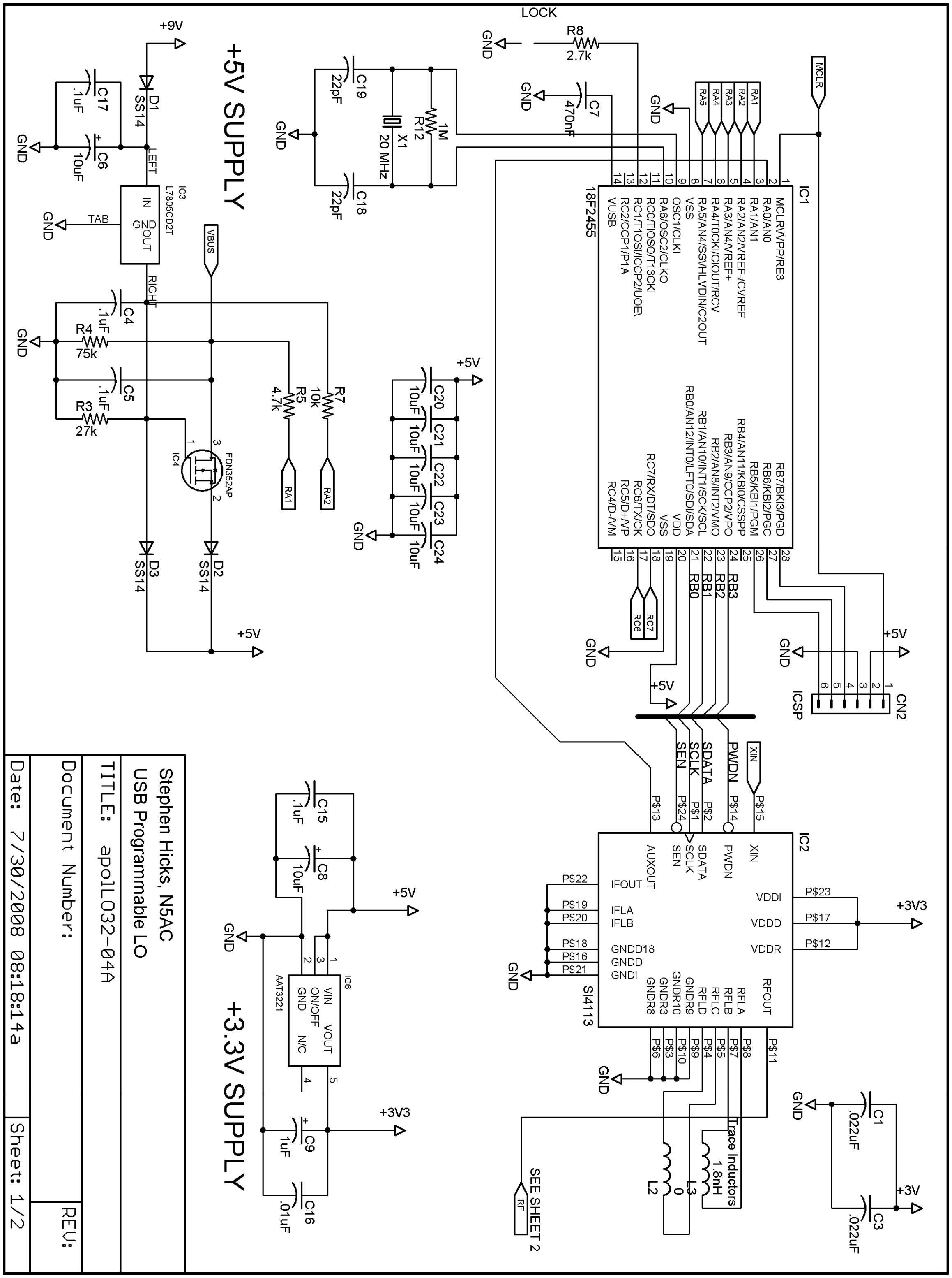
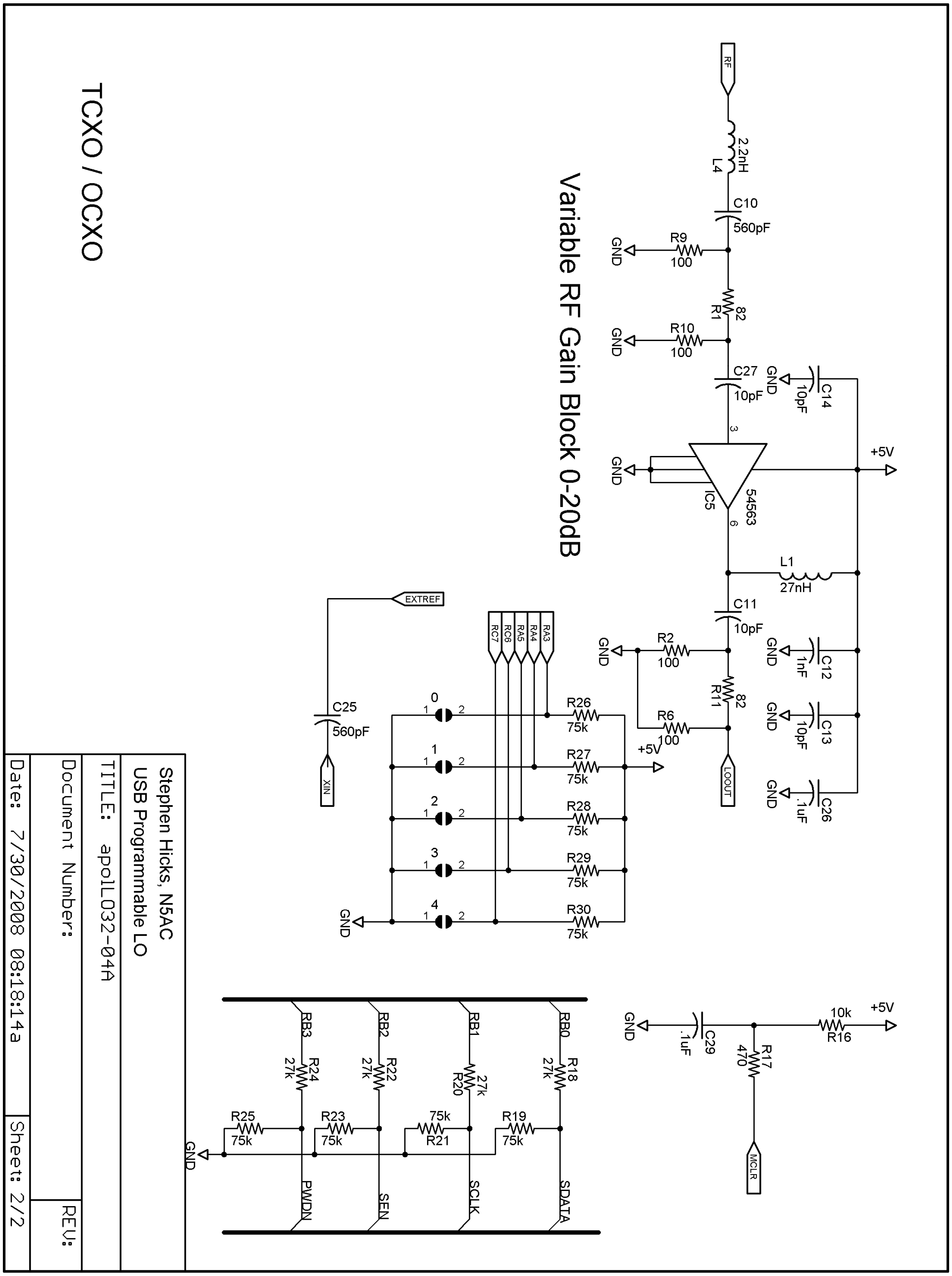



*Figure 7, apolLO with Z3801 10 MHz reference, 1136 MHz, 100 kHz phase detector update*

| Offset | 100 kHz | Difference / 1MHz |
|---|---|---|
| 10 Hz | -54 dBc/Hz | -16 dBc/Hz |
| 100 Hz | -68 dBc/Hz | -3 dBc/Hz |
| 1 kHz | -75 dBc/Hz | -7 dBc/Hz |
| 10 kHz | -81 dBc/Hz | -8 dBc/Hz |
| 100 kHz | -110 dBc/Hz | +2 dBc/Hz |
| 1 MHz | -128 dBc/Hz | +14 dBc/Hz |


+5V SUPPLY
+3.3V SUPPLY
Stephen Hicks, N5AC
USB Programmable LO
TITLE: apolLO32-04A
Document Number:
REV:
Date: 7/30/2008 08:18:14a
Sheet: 1/2


TCXO / OCXO
Variable RF Gain Block 0-20dB
RF
L4
2.2nH
C10
560pF
R9
100
R1
82
R10
100
C27
10pF
C14
10pF
IC5
54563
L1
27nH
C11
10pF
R2
100
R11
82
R6
100
C12
1nF
C13
10pF
C26
.1uF
LOOUT
+5V
GND
EXTREF
C25
560pF
XIN
RC7
RC6
RA5
RA4
RA3
R26
R27
R28
R29
R30
75k
R16
10k
R17
470
C29
.1uF
MCLR
RB3
RB2
RB1
RB0
R24
R22
R20
R18
27k
R25
R23
R21
R19
PWDN
SEN
SCLK
SDATA
Stephen Hicks, N5AC
USB Programmable LO
TITLE: apolLO32-04A
Document Number:
REV:
Date: 7/30/2008 08:18:14a
Sheet: 2/2

# JUMPER SETTINGS

| Band | 1 | IF | | Synth | Frequency | 4 | 3 | 2 | 1 | 0 | | R | N | Phase Det, kHz | PN, dBc/Hz @ 10Hz | PN, dBc/Hz @ 1 kHz |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2304 | | 144 | 1 | 1 | 1080 | | | | X | X | 3 | 1080 | 10 | 1000 | -67 | -80 |
| " | | 145 | 2 | 1 | 1079.5 | | | X | | X | 5 | 2159 | 20 | 500 | -65 | -79 |
| " | | 147 | 3 | 1 | 1078.5 | | X | | | X | 9 | 2157 | 20 | 500 | -65 | -79 |
| 2320 | * | 144 | 4 | 1 | 1088 | | | X | X | X | 7 | 1088 | 10 | 1000 | -70 | -81 |
| 2424 | * | 144 | 5 | 2 | 1140 | | X | | X | X | 11 | 1140 | 10 | 1000 | -70 | -81 |
| 3456 | | 144 | 6 | 2 | 1104 | | | X | X | | 6 | 1104 | 10 | 1000 | -70 | -81 |
| " | | 145 | 7 | 2 | 1103.666666 | | X | | X | | 10 | 3311 | 30 | 333 | -62 | -78 |
| " | | 147 | 8 | 2 | 1103 | X | X | X | X | | 30 | 1103 | 10 | 1000 | -70 | -81 |
| 3400 | * | 144 | 9 | 1 | 1085.333333 | | X | X | X | | 14 | 1628 | 15 | 667 | -67 | -80 |
| " | * | 145 | 10 | 1 | 1085 | X | X | | X | | 26 | 1085 | 10 | 1000 | -70 | -81 |
| 5760 | | 144 | 11 | 2 | 1123.2 | | X | X | | | 12 | 2808 | 25 | 400 | -64 | -78 |
| " | | 145 | 12 | 2 | 1123 | | X | X | | X | 13 | 1123 | 10 | 1000 | -70 | -81 |
| " | | 147 | 13 | 2 | 1122.6 | | X | X | X | X | 15 | 5613 | 50 | 200 | -59 | -76 |
| " | | 432 | 14 | 1 | 1065.6 | X | | | X | | 18 | 2664 | 25 | 400 | -64 | -80 |
| " | | 435 | 15 | 1 | 1065 | X | | | | X | 17 | 1065 | 10 | 1000 | -60 | -78 |
| 10368 | All Open | 144 | 16 | 2 | 1136 | | | | | | 0 | 1136 | 10 | 1000 | -72 | -87 |
| " | | 145 | 17 | 2 | 1135.888888 | X | | | X | X | 19 | 10223 | 90 | 111 | -60 | -77 |
| " | | 147 | 18 | 2 | 1135.666666 | X | | X | | | 20 | 3407 | 30 | 333 | -62 | -78 |
| " | | 432 | DUPE | 2 | 1104 | | | X | X | | 6 | 1104 | 10 | 1000 | -70 | -81 |
| " | | 435 | DUPE | 2 | 1103.666666 | | X | | X | | 10 | 3311 | 30 | 333 | -62 | -78 |
| " | | 1296 | 19 | 1 | 1008 | X | | X | | X | 21 | 1008 | 10 | 1000 | -70 | -81 |
| 24192 | | 144 | 20 | 1 | 1002 | X | | X | X | | 22 | 1002 | 10 | 1000 | -70 | -81 |
| " | | 147 | 21 | 1 | 1001.875 | X | X | | | | 24 | 1603 | 16 | 625 | -60 | -85 |
| " | | 432 | 22 | 1 | 990 | X | X | | X | X | 27 | 990 | 10 | 1000 | -70 | -81 |
| " | | 435 | 23 | 1 | 989.875 | X | X | X | | | 28 | 7919 | 80 | 125 | -56 | -75 |
| 24048 | | 144 | 24 | 1 | 996 | X | | X | X | X | 23 | 996 | 10 | 1000 | -70 | -81 |
| " | | 147 | 25 | 1 | 995.875 | X | X | | | X | 25 | 7967 | 80 | 125 | -56 | -75 |
| " | | 432 | 26 | 1 | 984 | X | X | X | X | X | 31 | 984 | 10 | 1000 | -70 | -81 |
| " | | 435 | 27 | 1 | 983.875 | X | X | X | | X | 29 | 7871 | 80 | 125 | -56 | -75 |
| 903.1 | 1 | WSS | 28 | 1 | 903.1 | | | | | X | 1 | 9031 | 100 | 100 | -60 | -79 |
| 915 | 2 | WSS | 29 | 1 | 915 | | | | X | | 2 | 915 | 10 | 1000 | -70 | -83 |
| 1296.1 | 3 | WSS | 30 | 2 | 1296.1 | | | X | | | 4 | 12961 | 100 | 100 | -54 | -74 |
| 1152.02 | 4 | WSS | 31 | 2 | 1152.022 | | X | | | | 8 | 10253 | 89 | 112 | -55 | -74 |
| 2401 | 5 | WSS | 32 | 2 | 1200.5 | X | | | | | 16 | 2401 | 20 | 500 | -68 | -88 |

## FINAL COMMENTS

I hope you enjoy your apolLO-32 board and I hope it serves your LO needs. If you should have any comments about the board, any recommendations or comments about the documentation, I would be interested in hearing them. Please send your comments to apollo@n5ac.com

Thanks & 73,
Steve, N5AC