

Zero-Phase Locking of Aeroflex Signal Generators

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1. Introduction

Heterodyne detection techniques, such as those employed in some frequency-domain photon migration (FDPM) experiments, require precise phase differences between source and detector. However, the problem with multiple signal generators (e.g., two Aeroflex signal generators configured as Master and Slave) is that the associated oscillators are typically not phase-locked together, and are not phase-referenced when powered on. We solve this problem with a straightforward combination of hardware and software. The proposed algorithm will set an absolute phase difference of zero between the two GPIB Aeroflex signal generators, permitting precise adjustment of phase shift during heterodyne detection.

A brief theoretical description of the problem is provided in the following section. A list of all parts is provided in Appendix A.

1.1. Theoretical Background

Our goal is to phase-lock two Aeroflex signal generators' sine waves that have a similar frequency and amplitude but a random phase difference. Given that the DAQ6229 board acquires data at a frequency of 10KHz and Aeroflex signal generators' frequencies used for the future experiments are greater than 1 MHz, the measurements are averaged. To address this random phase difference problem, we have based the phase locking on the multiplication of the two sine waves at the same frequency. We use a frequency mixer to multiply the two signals and then take a differential voltage measurement at the output.

Plotting the theoretical mean (see Fig. 1) of the multiplication of the two sine waves as a function of phase shift:

$$F(\varphi) = \text{Mean}_t(\sin(\omega \cdot t) \times \sin(\omega \cdot t + \varphi))$$

derives a sine shape, which is maximum when the two signals are in phase and minimum when they are out of phase. Theoretically, finding a minimum, maximum, or zeros should lead to phase-lock the two signals.

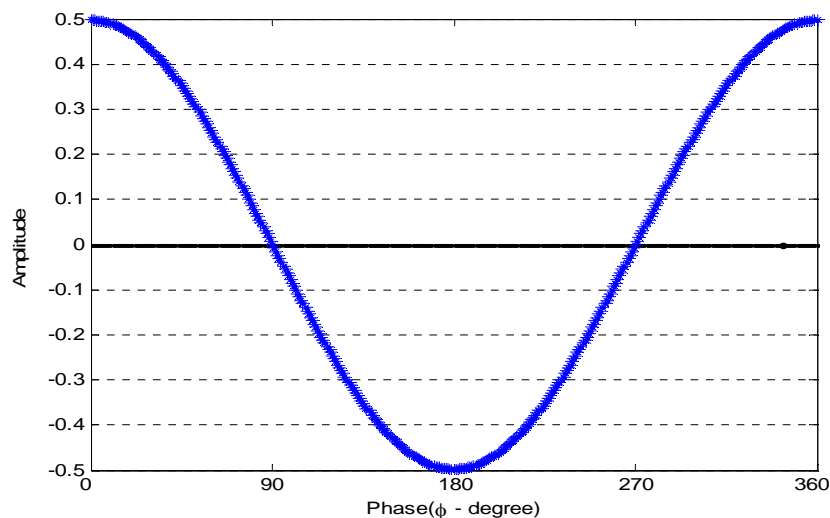


Figure 1. Theoretical mean of the multiplication of the two sine waves.

2. Experimental Setup, Results, and Analysis

In this section we describe the experimental setup that we used to phase-lock two signal generators. A detailed parts list for all the experiments described in this report is provided in Appendix A.

The summary of the experimental setup is given in Fig. 2 and the detailed list of steps one needs to follow to setup for this experiment is as follows:

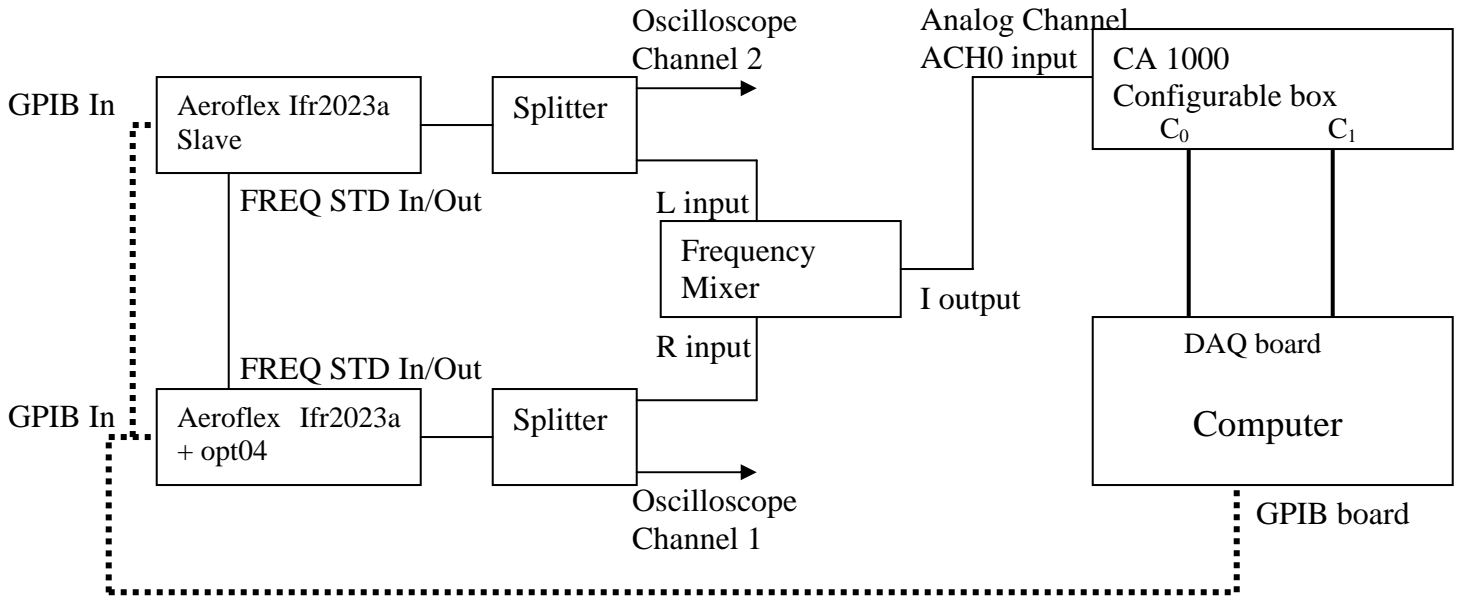


Figure 2. Block diagram of the experimental setup.

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- 1) Attach 110 V U.S.-type power cord to the back of each Aeroflex but keep the power switch off.
- 2) Attach one 12" BNC to BNC cable between each Aeroflex rear connector **FREQ STD IN-OUT** (see Fig. 3).
- 3) Attach one end of the 6' GPIB cable to your PC card and the other to the master Aeroflex rear GPIB connector (see Fig. 3).
- 4) Attach one end of the 3' GPIB cable to 6' GPIB cable at the master Aeroflex's end connector and the other end to the slave Aeroflex rear GPIB connector (See Fig. 3).
- 5) On each Aeroflex, attach one male-to-male N-type connector at the **RF OUTPUT** (see Fig. 4).
- 6) On each Aeroflex, attach the RF splitters input to the output of the previous N-type connectors (see Fig. 4).
- 7) On one output of each splitter attach an N male to a BNC female adapter (see Fig. 4).
- 8) For each previous adapter on each splitter, attach one end of a 24" male-to-male BNC connector and the other end to one input of the frequency mixer (L or R) (see Fig. 4).
- 9) Attach one end of the 48" BNC cable to the output of the frequency mixer (I), and the other end to the input labeled **ACH0** on the CA-1000 configurable box* (see Fig. 4).
- 10) Attach the SHC68-68-EPM cable to the corresponding input of the CA-1000 configurable box and to the PCI 6229 DAQ board on your computer.
- 11) Power on the master Aeroflex signal generator.
- 12) Wait until the master power up is complete (numbers on its screen).
- 13) Power on the slave Aeroflex signal generator.
- 14) Link the slave Aeroflex to the master Aeroflex. On the Master do the following:
 - Press **MENU**
 - Press **4** and Press **ENTER** (same button as Hz, rad, dB)
 - Press **4** to select the option **Internal; 10MHz out**
 - Press **CARR FREQ** to go back to the main screen
- 15) Link the slave Aeroflex to the master Aeroflex. On the slave do the following:
 - Press **MENU**
 - Press **4** and Press **ENTER** (same button as Hz, rad, dB)

* The configuration used for the CA-1000 Box is the **ACH0** differential. For this, on the connector 0 (C_0) pin-ends, you need to wire the (+) red wire to the **ACH0** channel (pin number 68); and the (-) black wire to the **ACH8** channel (pin number 34).

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- Press 1 to select the option Ext 10MHz direct
- Press CARR FREQ to go back to the main screen
- If everything is OK, you should see on the slave's screen "Ext" under "MHz"

16) Set the GPIB addresses. Do the following for each Aeroflex:

- Press MENU
- Press 51 and Press ENTER (same button as Hz, rad, dB)
- With the rotating knob choose the correct address for the corresponding Aeroflex:
- 1 for the master
- 2 for the slave
- Press CARR FREQ to go back to the main screen

17) Set the Remote operation control to GPIB. Do the following for each Aeroflex:

- Press MENU
- Press 50 and Press ENTER (same button as Hz, rad, dB)
- Press 0 to select the GPIB option
- Press CARR FREQ to go back to the main screen

☞ Note 1: The Aeroflex with the high stability OCXO crystal (OPTIONS FITTED 04 sticker on the back) will be called "Master"; the Aeroflex with the standard TCXO crystal (OPTIONS FITTED NONE sticker on the back) will be called "Slave" (See Fig. 3).

*☞ Note 2: Don't send a reset command (*RST) or else the GPIB address and the frequency link will be lost and must be reset manually.*

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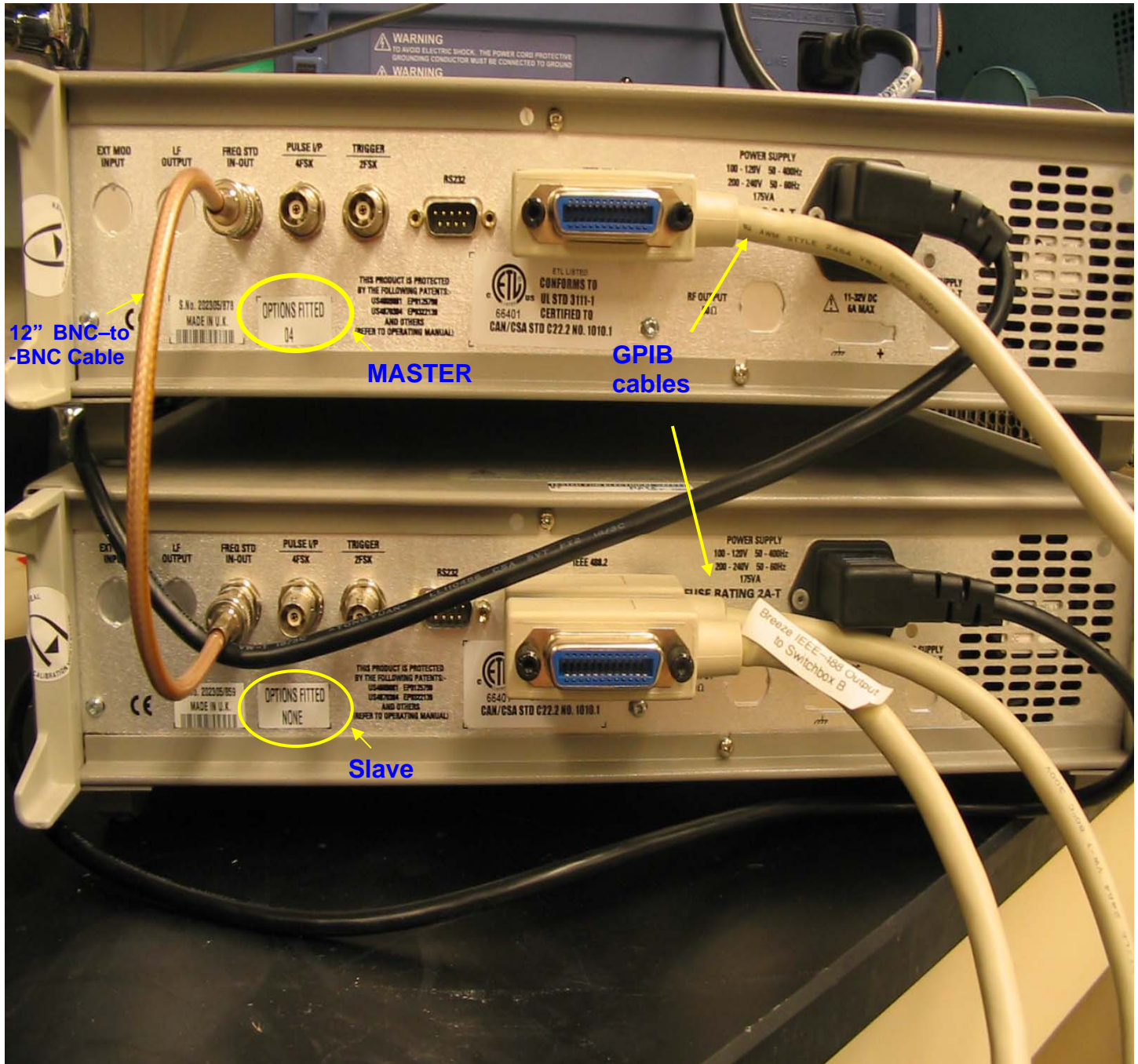


Figure 3. Two Aeroflex IFR2023A configured as master/slave. The 2023A unit with the “OPTIONS FITTED 04” sticker on the back is the “master” signal generator and the 2023A unit with “OPTIONS FITTED NONE” sticker on the back) is the “slave” signal generator. GPIB cables connect the Master signal generator to the slave and connect the Slave to the PC. The 12” BNC-to-BNC connects the two signal generators to one another.

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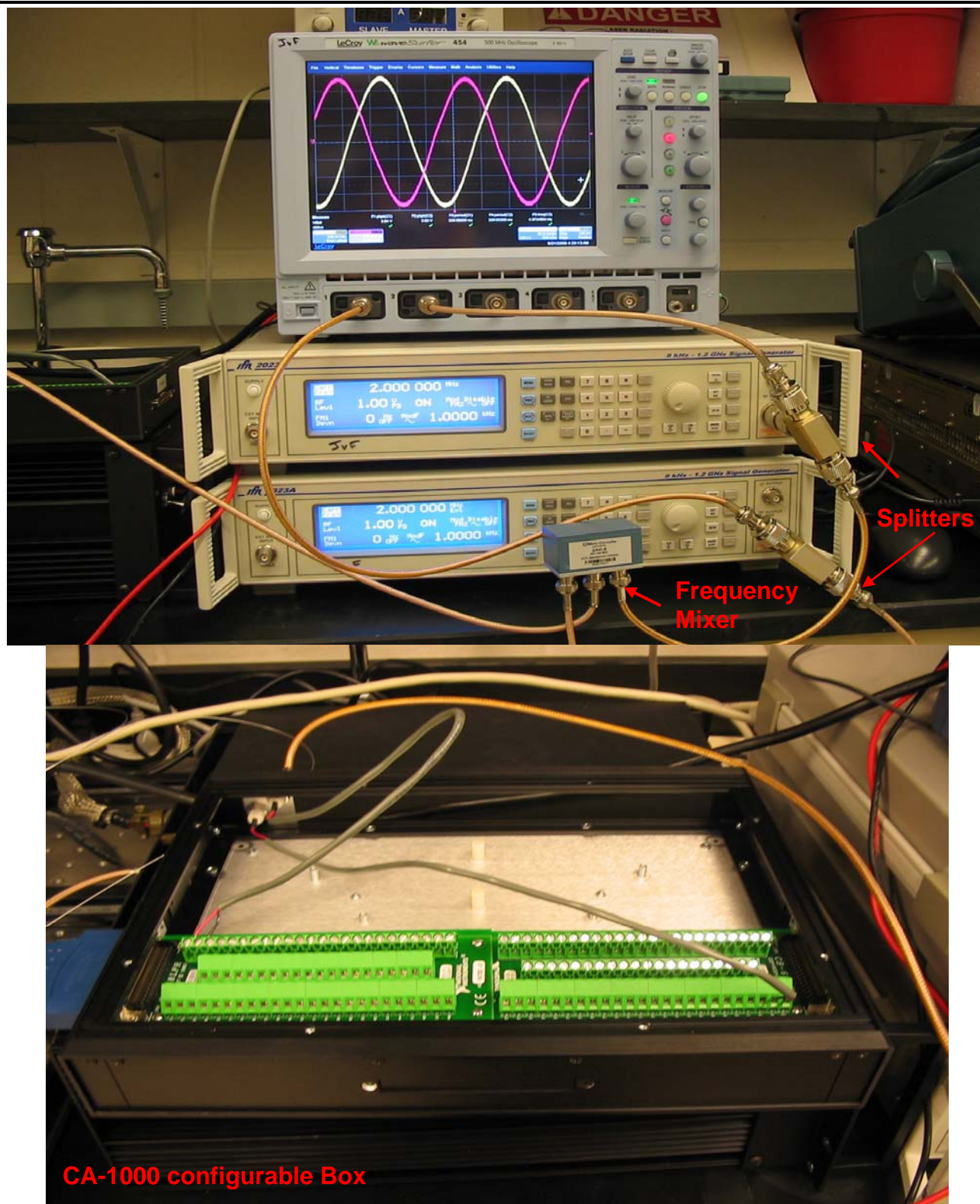


Figure 4. The RF output of each signal generator is fed into a 2-way splitter. Each new output is then connected to the digital oscilloscope and the frequency mixer. The output of the mixer is going to a CA-1000 configurable box.

2.1. Observations

The first important observation is that the mixer is negating the signal, i.e., phase lock is now at a minimum. The second important observation is that there is considerable noise in the system. The chosen solution for this problem is to average the signal (experimentally we chose 64 samples averaging). The shape of the signal is much more stable with this averaging.

Fig. 5 represents the output of the mixer with 64 samples averaging as a function of the phase shift in degrees (frequency 1MHz, amplitude 1V, 0.1 degree step-size).

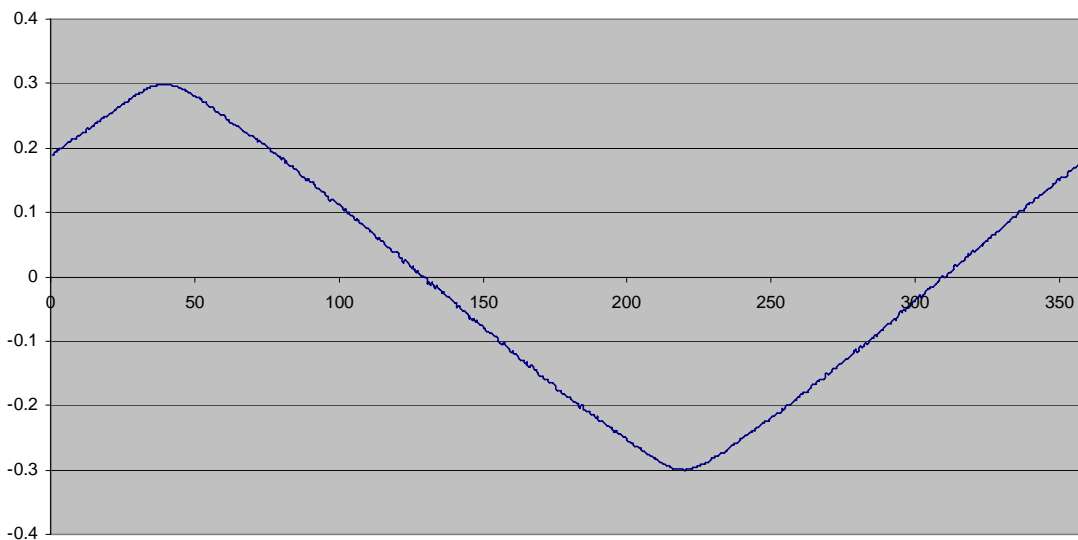


Figure 5. Output of the mixer.

Several important observations can be made:

- Even with an averaged signal there is still considerable noise for a 0.1 degree step-size.
- This implies uncertainties in finding a zero or a minimum.
- The output signal is not exactly a sine but has a strong linearity between its extrema.

Plotting now at a frequency of 100 MHz, which is the frequency used for the future experiments, leads to the results (frequency 100 MHz, amplitude 1V, 0.1 degree step-size) given in Fig 6:

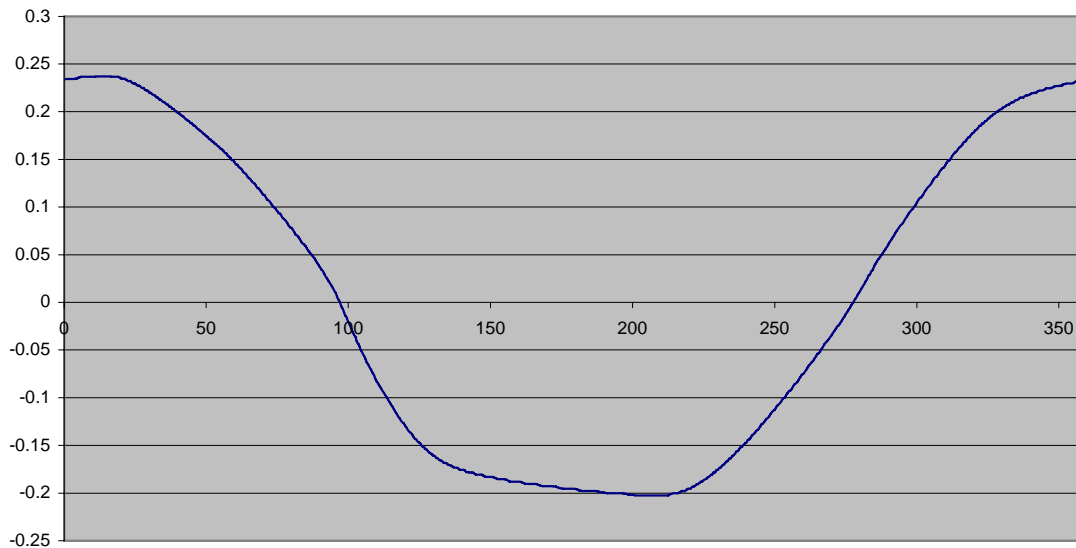


Figure 6. Phase function, frequency 100 MHz, amplitude 1V, 0.1 degree step-size.

Finding a minimum is no longer a possibility, since it is expected to be at a symmetrical position, and it is not. Finding zeros could still be a possibility since the curve seems to be still symmetrical near its inflexion points. However noise is still introducing uncertainties in the results, and the curve is not symmetrical relative to amplitude.

2.2. Proposed Algorithm

As shown before, finding the minimum is not a good way to solve this problem. First, finding a precise minimum requires a high precision in the phase steps and the noise in the system, even with a 64 samples averaging, leads to uncertainties, especially with very small step size. Second, as the frequency increases, the minimum is shifted from its phase-lock position.

One possible solution would be to filter the signal and to extract its frequency and phase. Unfortunately, using filtering tools in LabVIEW leads to a phase-shift of the reconstructed signal giving us uncertainties in finding the original phase.

The preferred solution is to find zeros in measured voltage. The original problem of finding zeros was the noise. Using 64 samples averaging and larger step-size solves this problem. Taking a large step-size results in fewer errors in high-slope areas and more errors in low-slope areas (extrema). In effect, it serves to average high slopes, which leads to an improved signal in the high-slope areas, where the zeros are. 64 samples averaging of data is still performed to increase the precision of the measurements. Data are acquired to keep only a “V” shaped curve with a minimum in its center and 360 degrees of phase shift, then offset in amplitude is corrected. Finally interpolating the two zeros and taking their middle point gives the phase-lock position.

This leads to the curve (frequency 100MHz, amplitude 1V, 10 degree step-size) shown in Fig 7:

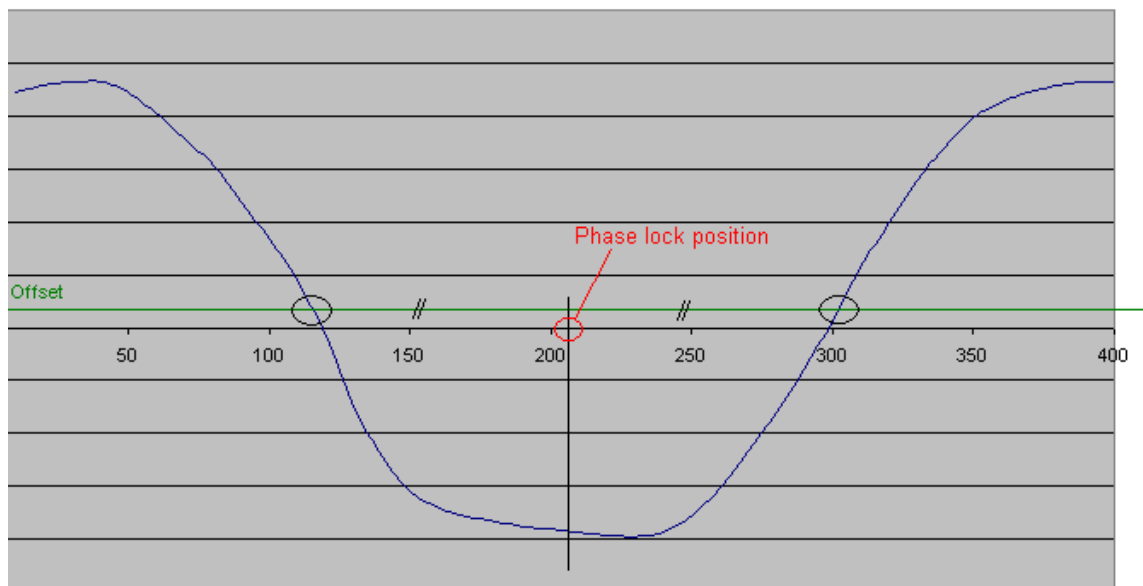


Figure 7. Corrected phase function (frequency 100MHz, amplitude 1V, 10 degree step-size).

A summary of the algorithm is as follows:

After setting the frequency and amplitude on each signal generator, phase steps of 10 degrees are performed with a measurement averaging of 64 samples. The measurement is recorded in two 36 elements arrays (one for the phase and the other for the measurement). Measurement is stopped when the phase shift curve is symmetrical with the “minimum” in its middle. DC offset is corrected so that the curve is also symmetrical around zero (relative to amplitude). Zero solutions are interpolated in the measurement array and the middle point is calculated. Finally, the corresponding phase-shift is interpolated on the phase array and the phase is set back to this value.

2.2.1. Software Description

Communication with the signal generators is provided by LabVIEW functions GPIB-write and GPIB-read. The reference of the code used for the communication can be found in the signal generator ifr2023a manual in Section 5.

This software assumes only that:

- The installation procedure has been fully performed (see Section 2).
- The GPIB address and frequency link have been correctly set (see Section 2).

The interface used to test the main sub-VI is Phase_Lock_MainVI.vi.

The main sub-VI that can be implemented in a larger VI is **Phase_Lock_SubVI.vi**.

This main sub-VI is linked to the following other sub-VIs :

- GPIB_Errors.vi, which identifies the errors in the Aeroflex signal generators.
- GPIB_Info.vi, which incorporate the two Aeroflex error information to the general error channel.
- Initialize_amp_freq.vi, which initialize amplitude and frequency for the two Aeroflex.
- Phase_Identifier, which is the main subVI and contains the phase finder algorithm.

The .vi files, a standalone executable file and a Readme.txt that includes instructions on how to run the program are included in this distribution. For instructions on how to run the program or the executable, please read the provided Readme file.

2.2.2. Testing and Performance

This algorithm has only been tested up to 100 MHz. It provides reliable results with good reproducibility. No unexplained phase offset has been observed within the limits of our measurement instruments. Finding the phase-lock position is fast (less than 5 seconds) and efficient.

2.2.3. Error Handling

The program is careful to scan for errors in hardware and software. The following special error cases were created:

- Error 9999: Low signal input: check the phase graph in the LabVIEW window, if it is abnormal, check all cables and make sure they are well plugged.

This error is generated when the difference between the highest and the lowest measurement is too low. You can disable this control manually in the LabVIEW window.

- Error 9998: Time out phase locking: check the phase graph in the LabVIEW window, if it is abnormal, check all cables and make sure they are well plugged.

This error is generated when the program does not find a sine wave that fits its requirements (minimum at 180 degrees) within 1500 degrees of phase shift.

- Error 9997: Aeroflex error: look on the Aeroflex front panel and in its manual for error description.

If such an error occurs, please run the program again. If it persists, look in the manual to find the corresponding error and call for support if you cannot fix it.

All other error messages are LabVIEW generated.

☞If you don't find any error in your setup, and if this program is not working, please contact us for support via email at info@frangionilab.org.

2.3. Recommendations and Final Notes

If the program finds an error, always make sure all the cables are well plugged, and that the GPIB address and master-slave link are correctly set.

The best way to be sure the program has run well is to look to the graph window. This window should plot a “V” shaped curve. Otherwise, there is a problem (plug or manual setting).

We have put a manual control on the low signal monitoring since it is possible, in rare cases, that it flags an error when no error is present. In this case run the program another time and if the problem persists, disable the low signal monitoring. If this problem is recurrent, please contact us at info@frangionilab.org.

We have found a hardware bug in the Aeroflex generators that was not previously known by the manufacturer. At the powering up of the generators, with a frequency standard link, the slave unit stores in its error status latch register a frequency standard error. Since our software is careful to find errors, this leads to the program stopping and displaying an error message during its first run. To bypass this problem, we had no other choice than directly querying the hardware condition register. However, this has the disadvantage of scanning only hardware errors. Other errors are much less probable and, if they occur, the program will not run properly and an error message will be visible on the signal generators' screens.

The final bandwidth of this system is limited by the individual components, and is presently 200KHz – 100MHz.

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Fig. 8 is a typical image of the LabVIEW window.

You notice two tandem “V” shape curves of different amplitudes. The one on the left corresponds to 10 MHz, and the one on the right to 100MHz.

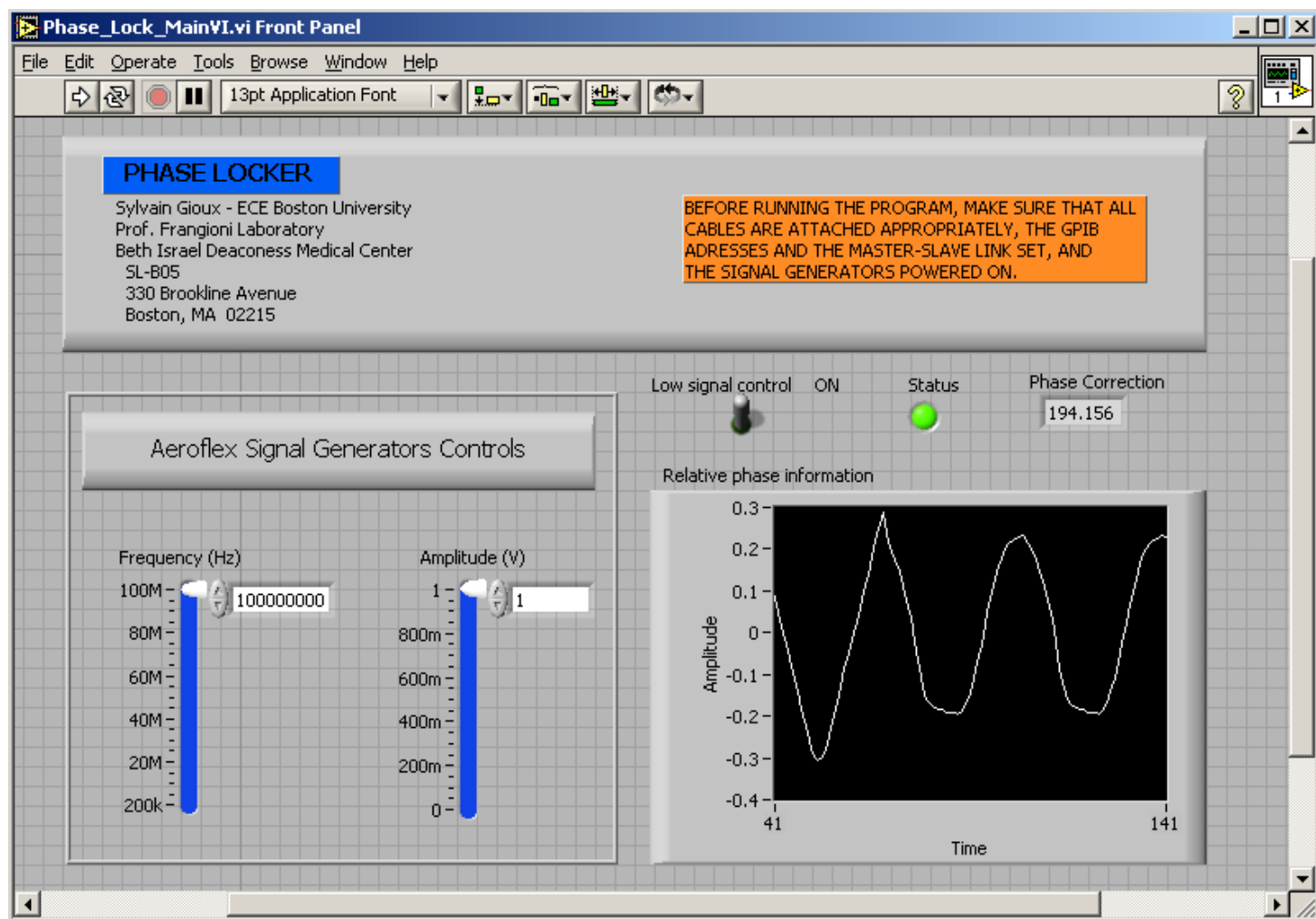


Figure 8. A typical image of the LabVIEW window.

The phase correction value corresponds to the calculated offset required to bring both generators in phase.

The status LED is green when everything is correct and turns red when a problem is detected.

Appendix A

Details of the parts used for the experiments described in this report are provided in this Appendix.

CATEGORY	QTY	ITEM	SUPPLIER	MANUFACTURER	MANUF. CATALOG#	UNIT COST	TOTAL COST
Signal Generator	2	RF signal generator (9 kHz - 1.2 GHz) w/ TCXO crystal	Aeroflex	Aeroflex	2023A	5,413	10,826
	1	High stability OCXO crystal for master 2023A	Aeroflex	Aeroflex	2023OPT4	464	464
Mixer	2	RF Splitter (0.2 MHz - 1 GHz), -3 db, female N/2 BNCs	Mini-Circuits	Mini-Circuits	ZFSC-2-4N	61	122
	1	RF Frequency Mixer (3 kHz - 100 MHz) w/ BNC connectors	Mini-Circuits	Mini-Circuits	ZAD-6	52	52
Connectors/ Cables	2	Male to Male N-type adapters (straight)	Pasternack	Pasternack	PE9007	8	16
	1	12" BNC to BNC cable, double shielded, 50Ω, RG400	Pasternack	Pasternack	PE3582-12	18	18
	2	24" BNC to BNC cable, double shielded, 50Ω, RG400	Pasternack	Pasternack	PE3582-24	20	40
	1	48" BNC to BNC cable, double shielded, 50Ω, RG400	Pasternack	Pasternack	PE3582-48	24	24
	4	N Male to BNC Female adapters (straight)	Pasternack	Pasternack	PE9002	9	36
Computer/ DAQ	1	GPiB interface board, PCI bus w/ 6' cable	Graftek	National Inst	778032-51	570	570
	1	3' GPiB cable	Graftek	National Inst	763061-01	75	75
	1	PCI-6229 multifcn DAQ board 32 A/In, 4 A/Out, 48 D/I/O	Graftek	National Inst	779068-01	679	679
	2	SHC68-68-EPM 68 pin to 68 pin breakout cable, 2 m	Graftek	National Inst	192061-2	120	240
	1	CA-1000 configurable breakout box w/ panelettes	Graftek	National Inst	777664-01	150	150
	2	CB-68LPR 68-pin screw terminal blocks for CA-1000	Graftek	National Inst	777145-02	95	190
	3	BNC panelettes (2 BNC per) for CA-1000, w/ pigtails	Graftek	National Inst	184737-01	15	45
	4	Banana jack panelettes (1 red/1black per) for CA-1000	Graftek	National Inst	186405-01	20	80
Total							\$13,693