Army Research Laboratory

Operations Manual for the National Center for Physical Acoustics Infrasound Microphone

by W.C. Kirkpatrick Alberts, II, Carrick L. Talmadge, Daniel Kleinert, and Roger Waxler

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14. ABSTRACT

The National Center for Physical Acoustics Infrasound Microphone is a self-contained microphone and data acquisition system for recording low frequency sounds. The sensor is rapidly deployable and contains a self-starting data acquisition and storage system. This manual discusses the proper procedures for unpacking, assembling, deploying, and operating this infrasound sensor in field environments.

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1. Introduction

The National Center for Physical Acoustics Infrasound Microphone (NCPA sensor) is a self-contained microphone and data acquisition system for recording low frequency sounds. The NCPA sensor is rapidly deployable, it can be powered by a 12 V battery and its data acquisition is self-starting.

The next section discusses the unpacking and initial setup of an NCPA sensor. Section 3 presents proper deployment procedures for an NCPA sensor. Section 4 presents procedures for configuring the data acquisition and for retrieving data and assessing its quality. The fifth section describes methods for retrieving sensors and preparing them for shipping.

2. Unpacking and Initial Setup

Upon unpacking the shipping container, the user will find, for each sensor in the array, a set of the equipment shown in figures 1a and b. In figure 1a, the components of an NCPA sensor are shown as they will arrive in the shipping container. (Note: the power cable that was shipped has clips fixed to their ends. A photo is found in appendix A.) The sensor, with cap installed, fits into a cube approximately 20 cm on a side. Of note is the small screw, just below the sensor head in figure 1a. This is one of four screws, removed for shipping, that seal the backing volume of the sensor. The screw and the vent are shown in greater detail in figure 2b. The sealing screws are #4-40 socket-head cap screws, ¼-in long. To assemble the sensor in preparation for deployment, the following procedures must be followed:

1. Inspect each of the vent screw holes around the circumference of the sensor head. Each hole should have a rubber washer, figure 2b. If a washer is not present in a hole, insert one from the washer bag included in the package.

2. Insert and tighten each of the four vent screws located around the circumference of the sensor head.

3. Depending on the circumstances of the measurement porous hose wind filters will be required of not. Different sensor caps are used:

   a. *NO POROUS HOSE REQUIRED* – The sensor cap has a series of small holes around its circumference as in figure 1a. Push the cap down over the sensor head until it is seated firmly.

   b. *POROUS HOSE REQUIRED* – The sensor cap has four garden hose fittings to attach the porous hoses to. Position the cap as shown in figure 1b (the end of the threaded nipple should be parallel to the base of the sensor) and push down until it is firmly seated, being careful to line up the holes in the cap and in the sensor head, and insert and tighten four #6-32 by ½-in screws located around the circumference of the cap.

4. *At the deployment site, just prior to deployment*, carefully install the antenna as shown in figure 1b.

5. *At the deployment site, just prior to deployment*, attach the power cable to the sensor as follows. Line up the indexing notch on the power cable with power receptacle on the sensor (the notch should be pointing upwards), figures 2a and b, push the cable until the locking ferrule on the cable comes in contact with the receptacle. Line up the indexing lugs on the ferrule with the notches in the receptacle and continue pushing the power plug until it is firmly seated in the receptacle. Turn the locking ferrule ¼ turn clockwise to lock the power plug. *Do not attempt to draw the plug in with the ferrule; this will damage both the plug and the receptacle.*

The sensor is now initially set up and ready for deployment, which will be discussed in the next section.

Figure 1. NCPA sensor as it will arrive in the shipping container (a), and assembled using the cap for attaching porous hose (b).

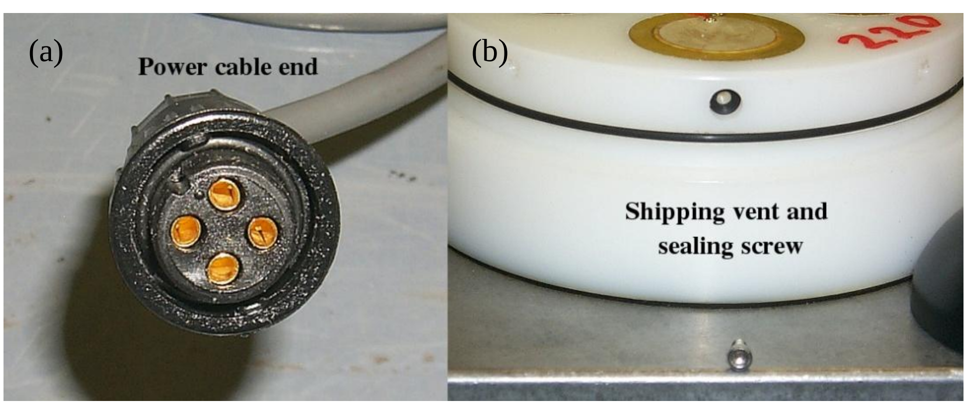

Figure 2. Detail of the power cable end (a), and of the shipping vent and sealing screw (b).

3. Deployment

Once a suitable site has been surveyed, and the unpacking and initial setup procedures for the NCPA sensors have been executed, follow the procedures set forth in one of the following sub-sections depending on the deployment conditions.

A. No Porous Hose Required

If porous hose is not required—e.g., the sensor array is to be deployed in a forest—the following procedures should be followed for each sensor position in a given array configuration:

1. Position the sensor on the ground. The sensor should be nominally level and have a view of the sky for proper GPS reception.

2. Position the battery as far from the sensor as the power cable will allow and attach the red alligator clip to the positive terminal of the battery and the black alligator clip to the negative terminal.

3. The sensor is now active and recording. Please proceed to section 4, which describes procedures for communicating with the sensors, for configuring the data acquisition, for transferring data files, and for viewing the files to verify proper operation of the sensor.

B. Porous Hose Required

If porous hose is required—e.g., if the sensor array is to be deployed in an area without significant tree cover or other vegetation to act as a natural wind screen such as a desert—the following procedures should be followed for each sensor position in a given array configuration:

1. Position the sensor on the ground well away from any buildings or other structures to mitigate vortex noise caused by wind flow around the structure. The sensor should be nominally level and have a clear view of the sky for proper GPS reception.

2. Make sure there is an o-ring on the inside of the porous hose connector. Firmly tighten the porous hose connectors (see figure 3) to the sensor cap until there is a good seal between the o-ring and the grey porous hose cap nipple. Do this by rotating the connector until you feel contact with the plastic nipple, then giving it approximately one-half more of a full rotation to insure good seal. It is crucial that the connectors are tightened until they seal against the o-ring gasket. *Spare o-rings have been shipped with the sensors and should be brought along because these sometimes fall out. Do not rely on the connectors to have the o-rings inside of them already.*

3. Unroll the hoses straight out from the sensor, figure 4. It is best to unroll the hoses "end-to-end," being careful not to leave or create kinks in the porous hose, which will inhibit the

ability of the hose to properly act as a wind screen. Attach the hoses to the sensor by sliding on the connector nipples as in figure 3. Make sure the hoses are on snugly. Make sure the hose is lying on the ground (no loops sticking up in the air). Sometimes rocks or sticks can be laid on “unruly” hoses to keep them lying flat.

4. Verify that other end of the porous hose is properly sealed with a black plastic stopper.
5. Position the battery as far from the sensor as the power cable will allow and attach the red alligator clip to the positive terminal of the battery and the black alligator clip to the negative terminal.

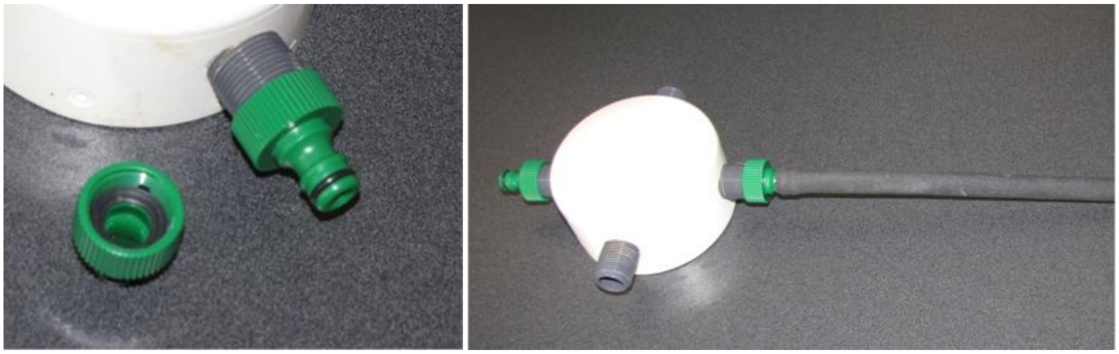

Figure 3. Connectors to attach porous hoses to sensor body.

Figure 4. Typical sensor deployment when porous hoses are required.

The sensor is now active and recording. Please proceed to section 4, which describes procedures for communicating with the sensors, for configuring the data acquisition, for transferring data files, and for viewing the files to verify proper operation of the sensor.

4. Acquisition Configuration, File Transfer, and Data Quality Assurance

This section describes the methods used to communicate with and configure the sensor as well as methods for retrieving and viewing data. The operating system on the data acquisition portion of the sensor is Linux-based. In the instructions that follow, the assumption has been made that the general user may have little or no knowledge of the Linux command-line. Thus, the commands will be discussed in greater detail than may be required by some users.

After the sensor is powered, allow a short time, on the order of 1–2 min, for the data acquisition to boot and obtain GPS lock. After that short period, communication with the sensor can be established via both a serial terminal and USB cable or via a wireless Internet connection. In the instructions that follow, italicized words represent commands to be given once logged into the sensor. Further, the italicized “*>*” represents the command prompt of the sensor. Throughout the instructions that follow, the letters “XXX” represent the last three digits of the IP address of a sensor, and are used as the sensor serial number. These three numbers are written in red on the sensor head, figures 1a and 2b, and in blue on the front panel of the sensor, figures 1a and b.

A. Accessing the sensor using a serial line and a USB connection:

1. Connect the cable to the sensor, figures 4 and 5. Follow the procedure for attaching the power cable.
2. For serial communication, open your favorite terminal emulator (in Windows this will be HyperTerminal).
3. Set the terminal to VT100 with a baud rate of 115200, 8 control bits, no parity, and one stop bit.
4. Hit enter and login as root with no password.

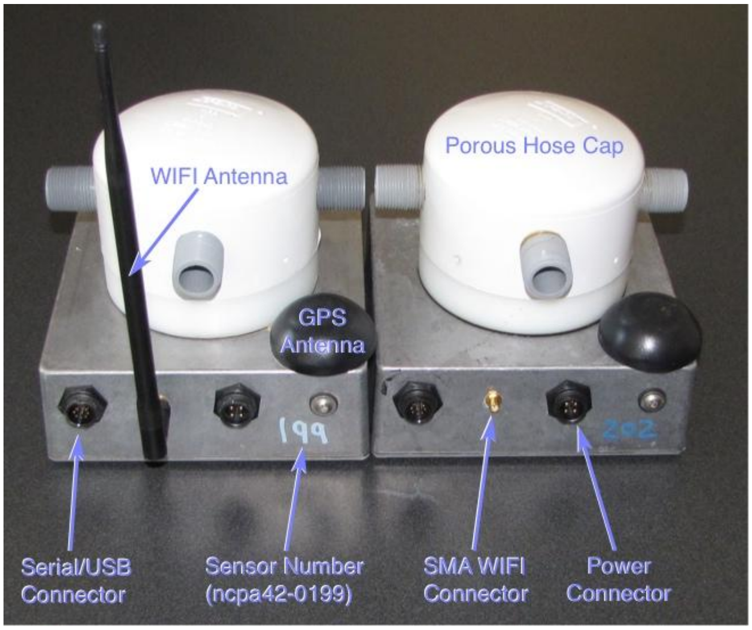

Figure 5. Detail of front panel of sensor case showing cable connection points.

B. Accessing the sensor using a wireless connection:

1. Set the WIFI in the laptop to operate over an ad hoc network.

2. Set the ESSID to be "ncpa-network".

3. Turn off DHCP.

4. Set the ip address of the laptop to 192.168.1.YYY, where YYY is a value between 2 and 15 (be sure that if you have more than one laptop on that they use different values for "YYY").

5. Restart the Internet services. A scan of the WIFI neighborhood should reveal the closest sensor. If several devices are accessible, you can use the command:

   >iwlist scan

   to scan for available devices on a Linux laptop. On Windows or Mac, you can use Angry IP Scanner. A zeroconfig-enabled scanner called "IP Scanner" is available for the Macintosh, however it is shareware (this program will show the actual sensor names in addition to their IP addressed).

6. Login to the sensor using (no password is necessary):

   >ssh root@192.168.1.XXX

C. Configuring and troubleshooting the sensor system:

1. Login to the system as above using either serial line or wireless connection.

2. List the contents of the home directory:

   >*ls*

3. The sensor configuration is stored in a file named UMSX1.4.cfg. The configuration file version, here 1.4, may be different. Choose the highest version. The likelihood is that the sensor will be fully configured for acquisition, with the possible exception of a descriptive tag, the variable *sensorLocation*, see appendix B, that is placed in the configurations file. To edit the configuration file the editor vi must be used. Those unfamiliar with vi basics should consult one of the many vi tutorials available on the web. It might be useful to download a vi command "cheat sheet". It is wise to make a backup of the file before editing by typing

   >*cp UMSX1.4.cfg UMSX1.4.cfg.backup*

   To recover the original form of the file type

   >*cp UMSX1.4.cfg.backup UMSX1.4.cfg*

   To open the configuration file for editing type:

   >*vi UMSX1.4.cfg*

4. Once inside the vi editor, use the "h, j, k, and l" keys or arrow keys to navigate to the line labeled "sensorLocation=". In the example file shown in appendix B the sensorLocation is "coldroom". Replace the name inside of the quotes with the appropriate descriptor for this sensor location (e.g., "TU1" for element 1 in Tunisia). The sensorLocation tag is not used to specify location, each sensor stores its GPS location inside of the recorded data files, but is helpful in troubleshooting.

5. To enable inserting of text, e.g. site name, type:

   >*i*

   Type the site name as normal. When finished hit the esc key. Navigate to the beginning of the old text and hit "x" until the old text is erased. If the editing is complete, hit "shift+ZZ"

6. To make the configuration changes active, type:

   >*ps –ef | grep UMX*

   Make note of the process ID (the number immediately following the word "root") of UMXcontrol and type:

   >*kill "process ID"*

   The UMXcontrol process will restart after a short time.

7. As a check, verify the restart by typing:
   >*ps –ef | grep UMX*

   If more than one UMXcontrol process is running, the sensor needs to be rebooted. Reboot using:
   >*reboot*

8. After the reboot is complete, login and verify that a single instance of UMXcontrol is running.

9. A second check to verify correct operation of the sensor is to transfer the latest data file to the laptop and then plot the file. To do this, follow the procedures described below, which depend on whether the sensor is accessed with serial port or through a wireless connection.

D. Data transfer using a USB drive and a serial port connection:

1. Attach a thumb drive that is verified to work with the sensor to the USB connector, which should mount the drive in */media/sda1*.

2. Verify that the USB drive mounted properly by issuing:> *df –h*

3. Copy the data from the latest date to your USB thumb drive using the command:
   >*cp –pr /data/ncpa42-0XXX_YYMMDD /media/sda1*

   where YYMMDD is the year, month, and day (e.g., January 22, 2011 would be 110122). Unmount the drive using the command:
   >*umount /media/sda1*

E. Data transfer using a wireless connection:

1. To retrieve data, for Windows can use a program such as FileZilla. On Linux or Mac, you can issue (on a laptop terminal) the command:
   >*rsync root@192.168.1.XXX:/data/ncpa42-0XXX_YYMMDD/ local-directory*

F. Plotting a data sample:

1. Convert the data file to ASCII by issuing (on a Linux or Macintosh laptop):

2. *>./umxcat pathname/data-filename > ascii-filename*

3. If you are using a Windows system, it will need CYGWIN and the umx executables installed. Alternatively a Windows system can view umx data with a Matlab script called *readumx*. If Cygnus Windows is installed on the Windows computer, the identical commands as used for Linux computers can be run. See appendix C for sensitivities of several possible configurations of NCPA sensors

4. Use any plotting software to plot the ASCII file. If the data resembles figure 6, then the sensor is operating correctly.

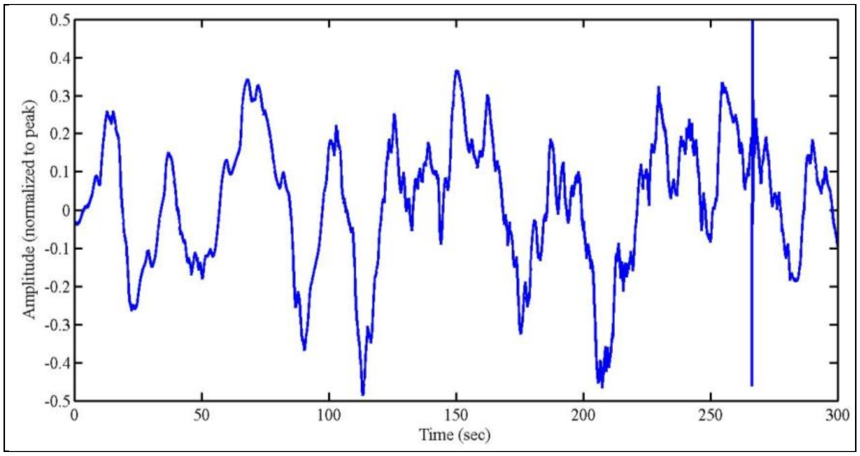

Figure 6. Typical wind noise response as measured by an NCPA sensor. The sharp feature at approximately 270 s is a small explosive event.

The sensor can now be left to operate on its own. When the experiment is over, access and log on to the sensor and retrieve all data to a USB memory stick (if accessed through the serial port) or to a laptop computer (if accessed wirelessly). After all data has been copied to the laptop the sensor is shut down by issuing the command

>halt

and waiting for 1–2 min.

5. Tear Down and Preparation for Shipping

After the data has been retrieved from each sensor and the sensor has been halted, the array is ready for tear down and shipping preparation. Follow the procedures below to properly tear down and pack for shipping.

A. No Porous Hose Required

1. Detach the power cable from the battery and the sensor.
2. Detach all other cables from the sensor (if used).
3. Detach the antenna (if used).
4. Gently push the blade of a flat bladed screwdriver into the seam between the sensor head and the cap.
5. Gently pry until the cap can be removed by hand.
6. Remove each of the 4 vent-sealing screws and return to their original envelope.

7. Return the sensors to their original packages wrapped as shown in figure 7.

B. Porous Hose Required

1. Detach the power cable from the sensor and battery.
2. Detach each of the four porous hoses.
3. Remove the four screws retaining the cap and return to their original envelope.
4. Proceed with steps 3–7, above.

Figure 7. Sensor wrapped for shipping back to NCPA.

Appendix A. Power Cable Photo

Figure A-1 shows a typical power cord used with the NCPA sensors. There is some variation in the type and size of the terminal clips used, but in all cases red is + and black is –.

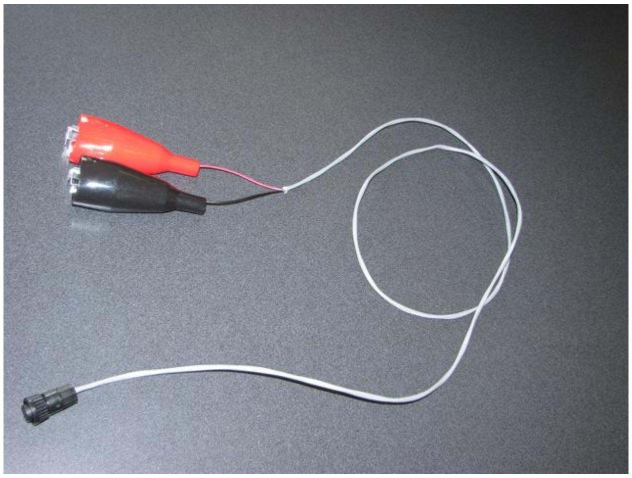

Figure A-1. Photograph of a typical NCPA sensor power cable.

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Appendix B. Configuration File Format

Note that the error checking and correction for this file by UMXcontrol is currently not robust. If you create a syntax error in your editing you might get an obscure message such as "!!!!! Cannot locate UMSX1.4.cfg !!!!!" (This weak error reporting is a limitation of the *libconfig* package currently used to read the configuration file.) It is highly recommended that you make a backup of this file before proceeding. It may also be more convenient to copy the file to your own system and edit locally.

Use this command from linux/mac/cygwin to copy the file to your computer:

scp –p root@192.168.1.1.XXX:UMSX.cfg .*

(For systems with no wireless, simply copy the cfg file to your thumbdrive.)

There are three sections of the configuration file that can be edited: sensorConfig, adcConfig and autoControl. Modifying any other portions of the config file will likely render the UMSX config file unusable. It is possible to just restart the sensor to get it to reread the config file with the updated information. You can also kill the UMXcontrol executable; it will automatically restart.

A. Format for sensorConfig:

sensorConfig =
{
magic = ".umx";
sensorName = "ncpa42-0147"; *sensor name*
sensorLocation = "coldroom"; *location information for sensor*
calibrationLevel = "25mv/Pa"; *sensitivity of mike*
calibrationDate = "NA"; *date of calibration. Here NA means "not applicable and signifies that the sensor is uncalibrated (nominal value is used instead).*
filePath = "/data"; *Directory where the data will be stored.*
UMXFileLength = 300; *size to make each file… in seconds. (a comment in some older cfg files shows this to be in minutes… that is incorrect.)*
};

B. Format for adcConfig:

adcConfig =
{
name = "LTC-2440";
sensorGain = 4; #[1..4]
sampleFrequency = 2; #[1..15]
};

Currently sensorGain is not implemented in hardware. Do not change the name, it is used to tag which analog-to-digital converted was used to digitize these data.

Currently supported values of sampleFreq:

2 – 1000 sps
3 – 500 sps
4 – 250 sps
5 – 125 sps
6 – 62.5 sps
7 – 31.25 sps
8 – 15.625 sps
9 – 7.8125 sps
15 – 3.90625 sps

C. Format for autoControl

```
autoControl =
{
    options = (
            { doSchedule = 0;          if nonzero, hourly scheduler is enabled
             doDaysOfWeek = 0; }       if nonzero, days of week scheduler is enabled
        );
     event is a comma-separated list of start and stop times for the day in the
     format HHMMSS.  This is enabled by setting doSchedule to a nonzero value.
    event = (     { start =      000000;
                   stop  =      010000; },
                  { start =      170000;
                   stop  =      240000; }
        );
     daysOfWeek is a list of days that you wish to record on.  Set to nonzero values
     to record on these days.  If doSchedule=0, this scheduler is disabled and data
     will be recorded seven days a week.
    daysOfWeek = ( {
            sunday = 0;
            monday = 1;
            tuesday = 1;
            wednesday = 1;
            thursday = 0;
            friday = 0;
            saturday = 0;
          }
        );
  };
```

Appendix C. Sensor Calibration and Frequency Response

Broadly, the tasks that the NCPA sensors perform can be separated into "far field" (<100 Pa signal strength), "regional" (<2500 Pa), "near field" (<6000 Pa), and "blast sensor" (<28000 Pa). As discussed previously, far field sensors can be configured to accept porous hoses that limit the high frequency response of the sensor or may have "high frequency" shrouds that allow more low frequency wind noise into the sensor.

New sensors are typically "seismically decoupled," which involve a set of two plates that have been matched to have the same pressure response, and are configured to cancel each other's seismic signal.

Sensors used near large sources typically will be seismically decoupled and have a high frequency shroud. Regional scale sensors may also have other types of wind noise abatement (e.g., a high frequency dome). Figure C-1 illustrates a number of different configurations.

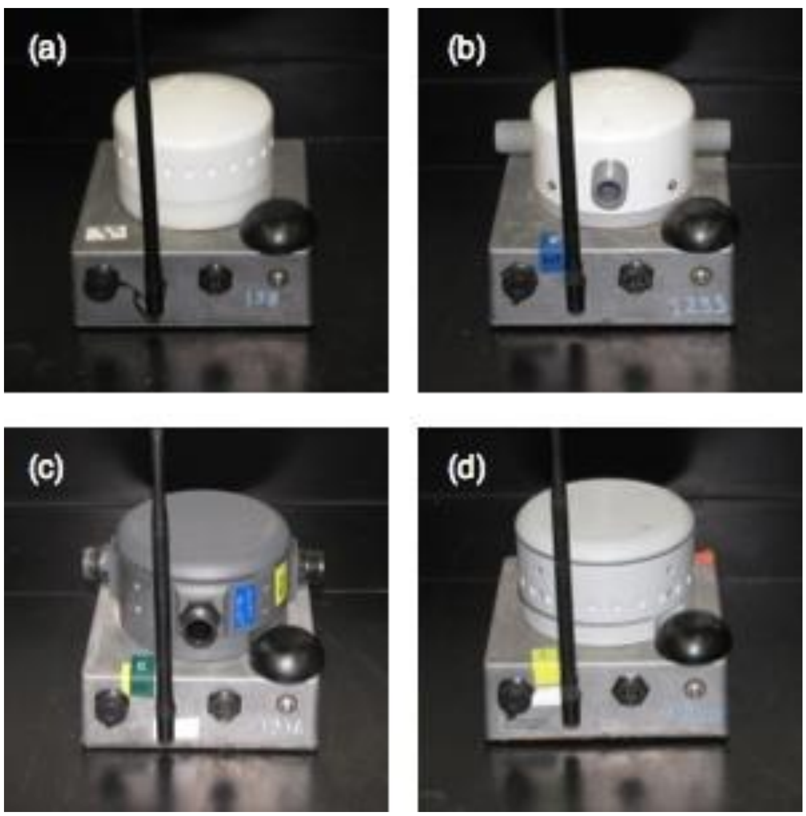

Figure C-1. Various NCPA sensor configurations. (a) Version 1.6 "white" sensor (base plate is white). (b) "Blue" single plate sensor. (c) "Green" seismically decoupled far-field sensor with porous hose connectors. (d) "Green" sensor with high frequency shroud.

Table C-1 gives the pole-zero structure for the NCPA digital sensors. The color code is used to demarcate the different configurations for the sensors. The sensitivity S0 is given in mV/Pa and frequencies are in Hz. Note that the maximum voltage of the ADC is 2.5 V, so the maximum transducible pressure for these digitizers is given by (2500 mV)/S0. Mathematically the form of the transfer function is given by:

$$S(f) = S_0 \times \frac{f}{f - if_0} \times \ldots \times \frac{f}{f - if_n} \tag{C-1}$$

Note that $S(f) \rightarrow S_0$ as $f \rightarrow \infty$ and $S(f) \rightarrow i^n$ as $f \rightarrow 0$, where i is the square root of negative 1 and n is the number of poles. Equivalently, the phase of $S(f) \rightarrow n\,\pi/2$ as $f \rightarrow 0$. Also note these results are for the convention $A(t) = A(\omega)e^{i\omega t} + cc$, where $\omega=2\pi f$ is the angular frequency and f is the ordinary frequency. Transfer functions for several of the different configurations of NCPA sensors are shown in figure C-2. As shown in the figure, the sensors, regardless of configuration, are all flat in sensitivity from 0.1 Hz to 10 Hz.

Table C-1. Sensitivity and pole structure for NCPA sensors. Note each sensor has an equal number of zeros as poles, with the zeros being located at the origin.

Color	Description	S0	f0	f1	f2
White	Single Plate (Far Field)	–25	0.00677	NA*	NA
Blue	Single Plate (Far Field)	–25	0.00149	0.00339	0.0295
Magenta	Single Plate (Regional)	–1.12	0.000284	0.00182	0.0128
Green	SD† (Far Field)	–25	0.00138	0.00267	0.0202
Yellow	SD (Regional)	–1.02	0.000135	0.0018	0.0125
Orange	SD (Near Field)	–0.52	$6.87\text{x}10^{-5}$	0.0018	0.0124
Red	SD (2-PSI Blast Sensor)	–0.172	$2.31\text{x}10^{-5}$	0.00179	0.0123
Red/White	SD (4-PSI Blast Sensor)	–0.086	$1.16\text{x}10^{-5}$	0.00179	0.0123

***Not Applicable**
†Seismically Decoupled

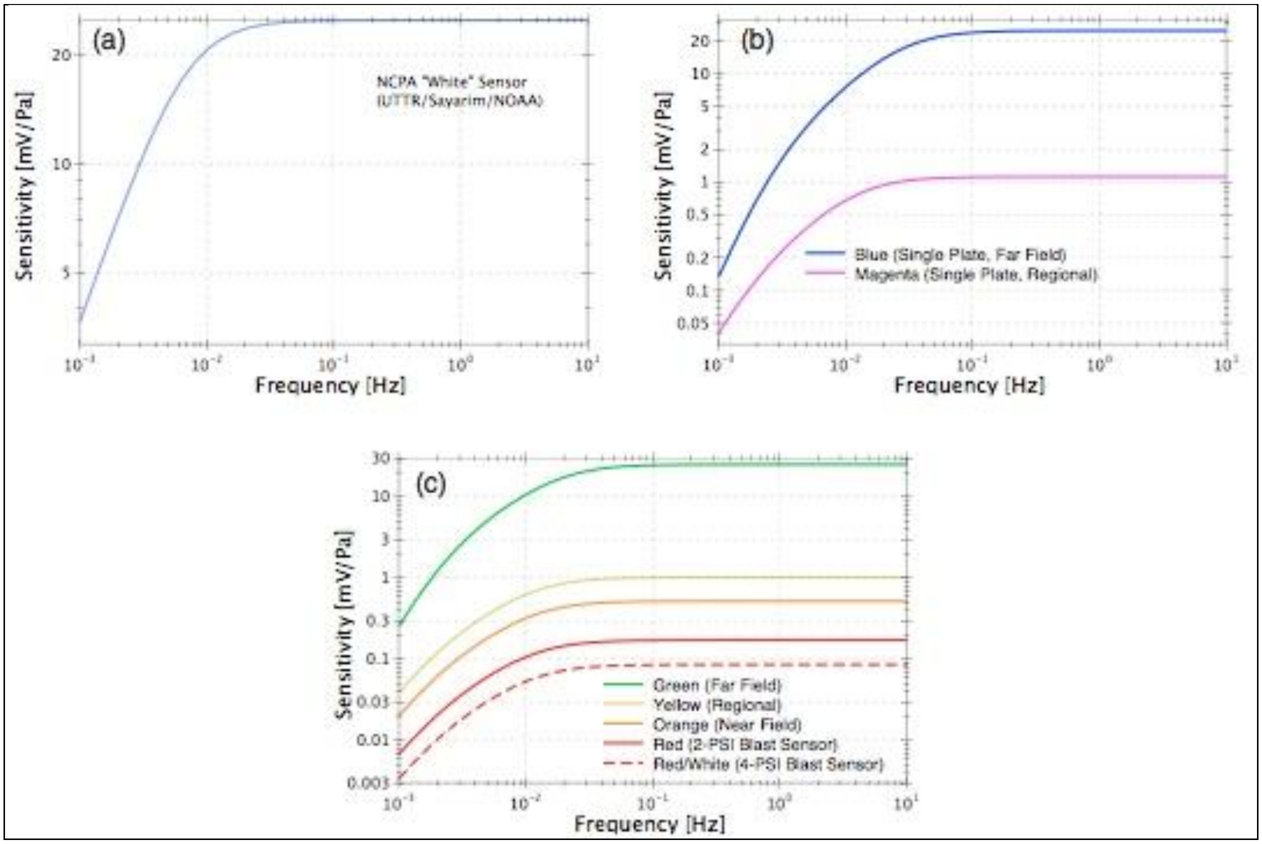

Figure C-2. Transfer functions for various NCPA sensor configurations. (a) White sensor, (b) single plate sensors, and (c) seismically decoupled sensors.

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