

IMU

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Notch

Gyro

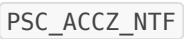
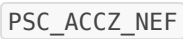


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1.  , , **2013-09-02.** ,
INS GYRO FILTER ().,

#.  **INS_HNTCH_ENABLE ** and/or **INS_HNTC2_ENABLE **,**
[site wiki="copter"] #. Attitude rate PID loop filtering of reference inputs, controlled by
****ATC_RAT_RLL_NTF, ATC_RAT_PIT_NTF and ATC_RAT_YAW_NTF.** Attitude rate PID loop
filtering of error inputs is controlled by **ATC_RAT_RLL_NEF, ATC_RAT_PIT_NEF and**
ATC_RAT_YAW_NEF. For altitude acceleration control, use  and  on
firmware before 4.7.0, or **PSC_D_ACC_NTF and PSC_D_ACC_NEF** on firmware 4.7.0 and later.
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As discussed in **common-measuring-vibration** section, there are basically two classes of noise/vibrations: those generated within the bandwidth of the gyros/accelerometer sampling and noise above those frequencies which are "aliased" down to within that bandwidth and can cause the "leans". The aliased noise must be eliminated at the source with improved mounting or frame rigidity, but the above filters can deal with the other sources, typically generated from the motor/propellers at their rotation frequency and its harmonics.

For multicopters and QuadPlanes, virtually all vibrations originate from the motor's rotational frequency. For helicopters and planes, the vibrations are linked to the main rotor/prop speed.

ArduPilot has support for two dynamic harmonic notch filters whose filter frequency can be linked to the motor rotational frequency for motors, or the rotor speed for helicopters, and provides notches at a primary frequency and its harmonics. And support for eight static notch filters: four at the rate PID target inputs and four at the rate PID error inputs. These are useful for eliminating frame harmonic resonances.

While the lowpass filters can effectively diminish the impact of this noise, having low frequency set points creates a lot of phase lag and therefore reduces how aggressive the tune can be before oscillation occurs, which results in a poorer tune.

For the gyro based rate controllers, this reduces their ability to respond to fast disturbances. If the gyro lowpass filter can be set higher, the phase lag induced is lower and the tune can be more aggressive. But this allows more noise and vibration, effectively canceling that gain out. Enabling either one or both of the Harmonic Notch filters gives the ability to target the noise generated by the motors, allowing a higher frequency of the following low pass to be set and therefore allowing tighter tune.

Notch Filter Setup Overview

1. **Enable the notch filter.** This makes the mode-specific setup parameters visible after a reboot.
2. Select how the notch center frequency will be controlled. See **center_freq_control**.
3. If a static notch (not usually recommended), or **throttle-based** control is used, the dominant noise frequencies will need to be determined in order to setup the notch. See **notch_center_freq**.
4. Setup the selected center frequency control method using **INS_HNTCH_MODE ****. Then **setup its associated parameters by reading its associated page linked in this section **center_freq_control**.
5. After a test flight and log analysis with the notch enabled (See **notch_check**), the **number and placement of higher harmonic filters implemented can be adjusted **, the use of the **multi-notch options**, or even a second harmonic notch set (**INS_HNTC2_ENABLE**) can be configured to improve noise reduction effectiveness. The web based [Filter Review Tool](#) can be used to experiment with parameter changes based on the test flight log to determine best configurations without having to make iterative test flights.

Enabling the Notch Filters

The harmonic notch is enabled overall by setting **INS_HNTCH_ENABLE = 1** for the first notch, and, if needed, a second set of harmonic notches using **INS_HNTC2_ENABLE = 1**. After rebooting, all the relevant parameters will appear.

Various methods of dynamically adjusting the notch(s) center frequency to track motor speed under different thrust conditions is provided, ie Dynamic Harmonic Notch filtering.

Notch Filter Control Types

Key to the dynamic notch filter operation is control of its center frequency. There are five methods that can be used for doing this:

1. **INS_HNTCH_MODE ** = 0. **Static center frequency.** Dynamic notch frequency control is disabled. The center frequency is fixed and is static. Often used in Traditional Helicopters with external governors for rotor speed, either incorporated in the ESC or separate for ICE motors.
2. **INS_HNTCH_MODE ** = 1. (Default) **Throttle position based,** where the frequency at hover throttle is determined by analysis of logs, and then variation of throttle position above this is used to track the increase in noise frequency. See **throttle-based** for further setup details.



this type of notch filter cannot be used in Traditional Helicopters since throttle stick position does not relate to motor throttle, but rather collective and will result in a configuration error being declared at boot. The **Static center frequency** type is usually used since helis usually use constant motor speed.

3. **INS_HNTCH_MODE ** = 2 (RPM Sensor 1) or 5(RPM Sensor2). **RPM sensor based,** where an external **RPM sensor ** is used to determine the motor frequency and hence primary vibration source's frequency for the notch. Often used in Traditional Helicopters (See **Helicopters)** using the ArduPilot Head Speed Governor feature. See **RPM Sensor** for further setup instructions.
4. **INS_HNTCH_MODE ** = 3. **ESC Telemetry based,** where the ESC provides motor RPM information which is used to set the center frequency. This can also be used for the forward motor in fixed wing flight, if the forward motor(s) ESCs report RPM. This requires that your ESCs are configured correctly to support BLHeli telemetry via **a serial port**. See **ESC Telemetry** for further setup instructions. If **INS_HNTCH_OPTS**, or **INS_HNTC2_OPTS** if the second set of notches is enabled, has bit 1 set, then a set of notches for each motor will be created, tracking its RPM telemetry, otherwise, the average frequency of all motors will set the center frequency.
5. **INS_HNTCH_MODE ** = 4. **In-Flight FFT based,** where a running FFT is done in flight to determine the primary noise frequency and adjust the notch's center frequency to match. This probably the best mode if the autopilot is capable of running this feature. It requires that the autopilot firmware supports it (see **common-limited_firmware** for GyroFFT feature) and has sufficient cpu power (F7/H7 autopilots). See ****In-Flight FFT **** for

further setup instructions.

ESC RPM telemetry is generally the best source of frequency data because it automatically adapts to varying payloads and is the easiest method to set up. Its only disadvantage is that the ESCs must provide fast and reliable RPM information. If the RPM data has a slow update rate or is unreliable, then another method should be used. The second-best method is throttle-based notch filtering. It has no update lag whatsoever, but its configuration is more complex and requires correctly setting ****MOT_SPIN_MIN**** and ****MOT_THST_EXPO****. If either parameter is incorrectly set, the notch center frequency will not match the motor frequency and its effectiveness will be reduced. Throttle-based notch filtering also requires retuning whenever the payload changes, because the ****INS_HNTCH_REF**** and/or ****INS_HNTC2_REF**** parameter must be changed.

All of the above are repeated, independently, for the second notch and are prefaced with `INS_HNTC2_` instead of `INS_HNTCH_`. The following will explain setup for the first set of notches.

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only one filter can be mode 4(FFT).

Determining Notch Filter Center Frequency

Before actually setting up a dynamic notch filter, the frequencies that are desired to be rejected must first be determined. This is crucial if a static notch or **common-throttle-based-notch** is used. While the other methods do not require this knowledge before setting up their parameters, it can still be worthwhile as a comparison point for the post filter activation analysis of the filter's effectiveness.

Once the noise frequency is determined, the notch filter(s) can be further setup. Historically, **common-imu-batchsampling** has been used for this (also for slow cpu's like F4-based autopilots), logging short bursts of raw IMU data for spectral analysis.

As of firmware version 4.5 and later, a better method has been developed using continuous raw IMU data, if the autopilot is H7-based, and using a new web based tool. ****This method is now preferred****.

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if you see two noise peaks close together, it may be that your copter has significant yaw imbalance. See the ****Yaw Imbalance section****.

Number of Harmonics Filtered

- Set ****INS_HNTCH_HMNCS**** to enable multiple harmonic filters centered at up to 16x the base frequency (multiples of the center frequency) notches. For ESC ****INS_HNTCH_MODE**** tracking, each motor will get a set of these notches. If an octocopter sets up three harmonics, this results in $8 \times 3 = 24$ notch filters. Enabling triple notches (see below) would result in 72 filters! This would most certainly cause excessive cpu loading and performance issues. Other modes only provide a single set of harmonic notches.

Always enable only the number of harmonic notch filters actually required and be especially aware of what is being enabled if using ESC (****INS_HNTCH_MODE**** = 3) tracking mode. Enabling too many will result in running out of CPU cycles with unpredictable results. Three harmonics is usually safe.

Checking Notch Filter Effectiveness

Once the notch filter(s) are setup, the effectiveness of them can be checked by again measuring the frequency spectrum of the output of the filters (which are the new inputs to the IMU sensors). Refer back to the **common-imu-batchsampling** or **common-raw-imu-logging** page for this.

Multi Notch

The software notch filters used are very "spikey" being relatively narrow but good at attenuation at their center. On larger copters the noise profile of the motors is quite dirty covering a broader range of frequencies than can be covered by a single notch filter. In order to address this situation it is possible to configure the harmonic notches as multiple notches that gives a wider spread of significant attenuation. The configuration is controlled by the ****INS_HNTCH_OPTS**** parameter. This is a bitmask parameter and multiple options are possible at the same time, but using bit 0, 1, and bit 4 at the same time should be avoided. Use only one of those in a given configuration.

INS_HNTCH_OPTS Bit Action	
0	Double overlapping Notches

**INS_HNTCH_OPTS ** Bit Action	
1	MultiSource: if using FFT Mode, the three largest noise sources will have a notch assigned. If ESC Telemetry Mode, then each motor will have a notch assigned at its RPM. If throttle mode, then each motor will have a notch assigned at its throttle input rather than the average overall throttle.
2	Updates the filters at the loop rate. This is cpu intensive, but tracks noise variations faster. Only valid if frequency source updates at loop rate, ie Bi-Directional DShot telemetry.
3	Enables notches on every IMU instead of just the primary. This is cpu intensive, but allows better lane switching decisions in noisy situations and for debugging. Not recommended for F4 boards.
4	Triple overlapping Notches
5	If the RPM source fails (Sensor,ESC telem,FFT) the minimum frequency (FFT_MINHZ , INS_HNTCH_FREQ , or INS_HNTC2_FREQ) will be used for notch center frequency

double notch option is no longer recommended since the triple notch option has been added. With a double notch, the maximum attenuation is either side of the center frequency, so on smaller aircraft with a very pronounced peak their use is usually counter productive.

Each notch has some CPU cost so if you configure multiple notches you can end up with many notches on your aircraft. For example, triple single (no harmonics) notches, using ESC telemetry will result in 3 notches per motor or 12 total notches. For example, with F4 cpus this should be acceptable, but enabling a second group of triple notches with **INS_HNTC2_ENABLE** or multiple harmonic notches, could cause problems.



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