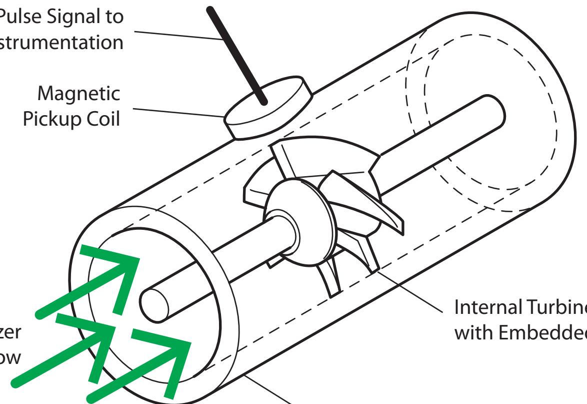
Signal Conditioning for Rocket Engine Fuel Flow Measurements

Introduction

NASA's John C. Stennis Space Center has tested rocket engines for more than 40 years. The testing performed at Stennis has been vital to the U.S. space program. The A and B test complexes house vertical stands that were used in the '60s to test Saturn-V rocket engines. During the shuttle era the stands were used to test the Space Shuttle Main Engine (SSME). Today, the center supports a variety of programs including testing of engines for the cutting-edge Space Launch System (SLS). This application note discusses the signal conditioning solution for the measurement of fuel flow to the engine under test.

To create thrust, chemical rocket engines require a combustible fuel and an oxidizer (like liquid oxygen). Accurately measuring the rate volume of an engine's fuel/oxidizer consumption is critical for measuring performance parameters of the rocket, such as specific impulse: the ratio of fuel mass consumed to thrust produced per second. Specific impulse measurements determine payload size and mission fuel requirements.



Simplified Diagram of a Turbine Flow Meter

A turbine flow meter in the fuel lines monitors fuel/oxidizer consumption. An internal turbine turns as fluid flows across the blades, and magnetic pickups generate electrical pulses. The pulse frequency of the flow meter output is proportional to the volumetric flow of fuel and oxidizer to the rocket engine.

Flow meter signals often have overshoot, ringing, and noise on the pulse signal, which makes reliable triggering and frequency measurement extremely difficult. The mechanism inside the flow meter produces noise with frequency content above and below the pulse signal. Variability in noise content from sensor to sensor creates new and evolving signal conditioning challenges.

After 30 years of service, the signal conditioning system for Stennis's test stands needed an upgrade. The legacy system failure rate was increasing, the repair costs were high, and many of the parts were no longer available. It was desired to have a replacement solution with computer programmable setup and one where automated on-site calibration could be performed.

To address changing flow measurement challenges and reduce system setup, verification, and maintenance costs, NASA chose Precision Filters' 28000 system with the 28524 Frequency-to-Voltage Converter and 28608B Filter/Amplifier for the front-end signal conditioning of its fuel flow monitoring system.

NASA Stennis B1/B2 Test Stand

Solution Highlights

- **Scalable, universal conditioning solution supports a variety of transducers in one high-density mainframe.**
- **Programmable band-pass filtering of flow-meter signals reduces out-band noise.**
- **Frequency-to-DC-voltage converter reliably measures flow meter pulse outputs to determine fuel/oxidizer volumetric flow.**
- **28000 FAT provides fully automated, *in situ* NIST-traceable calibration tests.**
- **28000 Go/No-Go test provides automated validation of signal conditioner settings.**

Rocket Engine Test at NASA Stennis

Solution

Precision's 28000 system supports a mix of signal conditioning cards for strain, shock, vibration, frequency-to-voltage, and anti-aliasing filters. As shown in the channel block diagram below, the fuel monitoring system front-end signal conditioning uses the 28608B Filter/Amplifier card configured with band-pass filters to buffer, amplify, and filter the flow meter pulse signals. The band-pass filter capability is effective at cleaning up the raw flow meter signal harmonics and noise prior to frequency conversion. Since each filter's cutoff frequency is independently controlled, the center frequency and bandwidth of the band-pass response can be changed to reject interfering signals and harmonics that vary from sensor to sensor.

The Precision 28524 Frequency-to-Voltage Converter card accurately measures the frequency of the flow meter signal and outputs a precise DC level proportional to frequency. The DC output range can be independently programmed for each channel, allowing users to scale the DC output to the flow meter frequency range of interest. The 28524 has four averaging time constants for the DC output, so users can select smoothed or rapid output response.

To deal with the most difficult flow meter signals, the 28524 card features a configurable trigger. Programmable trigger polarity (positive or negative), trigger hold-off (in seconds), and trigger level settings allow for reliable measurement of frequency on signals with ringing, overshoot, crossover distortion, or glitches.

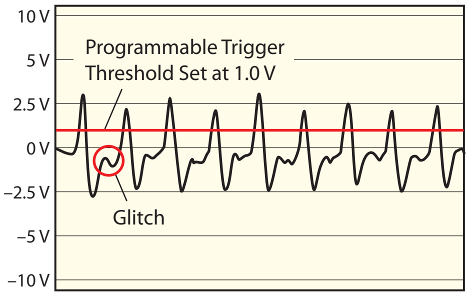
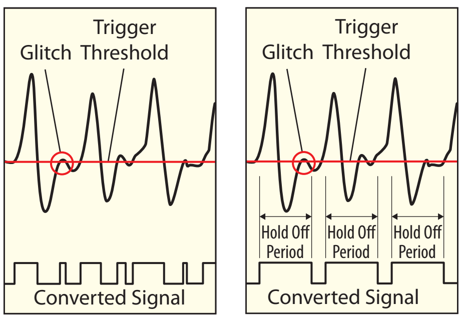


Figure 1: Programmable Trigger Threshold Set Above the Glitch

Figure 1 shows a signal from an actual flow meter. The expected periodic waveform is present, with a glitch in the middle of each signal cycle that has a slight variation from cycle to cycle. These glitches can cause false triggers by creating additional rising and falling edges near the zero crossing point at random zero crossings.

One method that provides reliable triggering is to set the 28524 trigger point above or below the glitch point in the signal cycle, as shown by the red line in Figure 1.

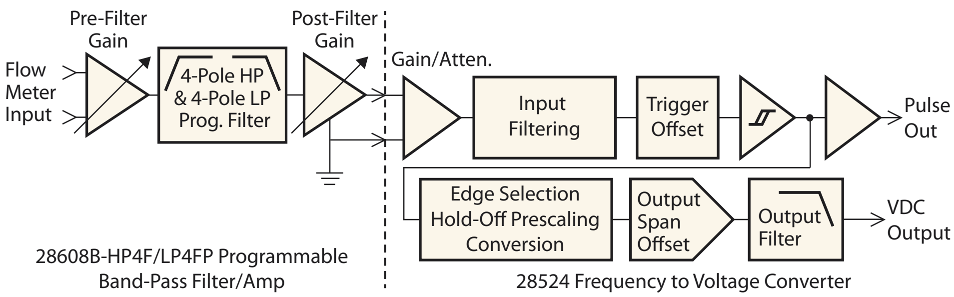
Another approach is the trigger hold-off feature as shown in Figure 2. The trigger circuit is disabled for the hold-off time to ignore false edges.



No Trigger Hold-Off Creates False Triggering

Trigger Hold-Off Enabled Prevents False Trigger

Figure 2: Programmable Hold-Off



Channel Block Diagram of NASA Stennis Flow Meter Signal Conditioner

For more information, please contact Doug Firth, Precision Filters, Inc. at 607-277-3550 or doug@pfinc.com.

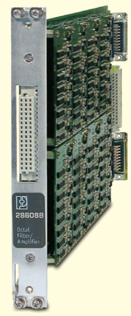
System Self-Test and Calibration

Precision Filters' built-in test capability lets users perform NIST-traceable calibration tests without removing the system from the equipment rack—saving NASA hours of pre-test manual validation. Every card function is exercised and all data-critical performance characteristics are measured and compared to published specifications.

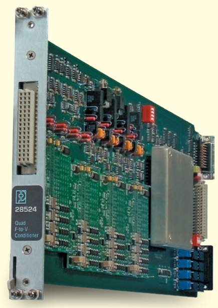
While the FAT verifies channel parameters, the Go/No-Go test quickly verifies each channel's run-time settings. Channel settings—including gain, filter setting, DC offset, and noise levels—are quickly measured, verified, and reported, proving that the equipment is functioning properly.

PFI Equipment Used for Rocket Engine Fuel Flow Tests

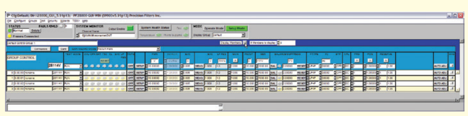
28016 Signal Conditioning System with 28000 Sub-Test System



28608B Filter/Amplifier Card



28524 Frequency-to-Voltage Converters



28000 Graphical User Interface (GUI)

PRECISION FILTERS, INC.
ISO 9001 CERTIFIED QUALITY

Precision Filters, Inc.
240 Cherry Street
Ithaca, New York 14850

Telephone: **607-277-3550**
E-mail: **pfinfo@pfinc.com**
Web Site: **www.pfinc.com**