Contents

ESD - Antistatic
All necessary antistatic precautions must be taken while handling circuit boards.

Version 1.0, 24 October 2008

Introduction

MoTeC's **Knock Modules** provide individual cylinder closed loop knock control, allowing tuners to safely optimise high performance ignition maps. There is a standalone module compatible with all 'hundred series' ECUs and a version specifically designed to mount onto an M800 Plug-In ECU. Both modules work in conjunction with MoTeC's ECU Manager software (v3.5 and up)

Standalone Knock Module (SKM)

This module is housed in a robust aluminium casing that can be mounted as required in any vehicle. It is wired between the ECU and the knock sensor.

Onboard Knock Module (OKM)

This module is fitted onto the board of an M800 Plug-In ECU prior to delivery and linked to the knock sensor. M800 Plug-In ECUs are available for selected vehicles. Please check our website at www.motec.com.au for details.

Basic Specifications

	SKM	*OKM*
Inputs	• Knock sensor input • Knock window input • Power supply 8 V	
Outputs	• Knock sensor out • Audio	• Audio
Physical	• Case size 38 x 90 x 25 mm excluding connector • Weight 100 grams • 1 x 13 pin Autosport connector	• Fitted onto a M800 Plug-In ECU

Other information

	SKM	OKM
Compatibility	• 'hundred series' ECUs; M400, M600, M800 and M880 • All knock sensors	• M800 Plug-In ECUs
Related software	• ECU Manager software v3.5 and up (software version 2.3 enables monitor only) • i2 Data Analysis • Gold Wave Audio Analysis Software (for frequency analysis only)	• ECU Manager software v3.5 and up (software version 2.3 enables monitor only) • i2 Data Analysis • Gold Wave Audio Analysis Software (for frequency analysis only)
Accessories	• Stereo headphones • Knock sensor • SKM tuning loom #61114 (optional)	• Stereo headphones

Getting Started

The Knock Modules have no stand-alone Manager software.

All knock control configuration is done through MoTeC's ECU Manager software (version 3.5 or up). This can be downloaded from the MoTeC website at www.motec.com . Further information on ECU Manager software can be found in the ECU User Manual

For frequency analysis MoTeC recommends Gold Wave Audio Analysis Software. A trial version can be downloaded from www.goldwave.com

PC requirements

- Operating System: Windows XP and up
- Audio and USB input
- Sound card capable of simultaneously recording and playing. Alternatively, an external soundcard or third party device can be used.

Installation

SKM

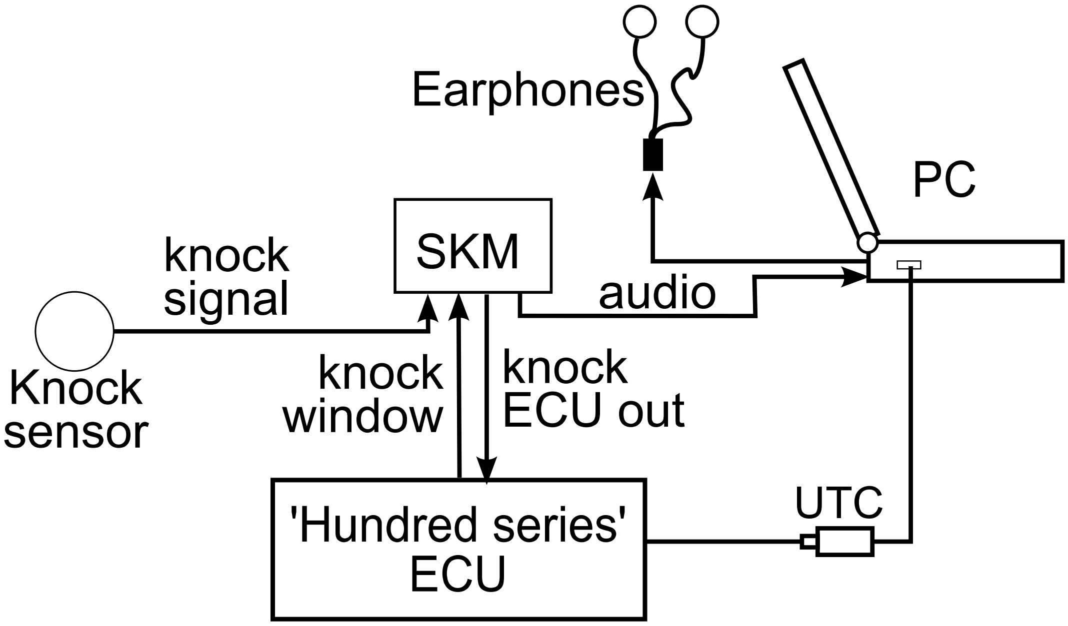
The SKM is connected between the OEM fitted knock sensor and a 'hundred series' ECU – M400, M600, M800 or M880.

The SKM knock signal output must be connected to the ECU via an available analogue voltage input, preferable a Lambda sense input. The Lambda sense input has a slightly higher resolution.

To send the gated window signal to the knock module connect a spare injector or ignition output on the M800 or M880 ECU to the SKM input. On the M400 and M600, injector 8 output must be used.

Alternatively the SKM Tuning loom can be used (available separately)

See appendix 2 and 3 for detailed wiring instructions



OKM

The OKM is fitted directly onto the board of an M800 Plug-In ECU.

Most M800 Plug-In ECUs fitted with an OKM are pre-configured to analogue voltage input AV5 and ignition output 6. WRX9/10 boards use lambda 1 sense input rather than AV5.

Configuration

When suffering detonation, each engine/chassis combination and associated accessory package resonates at different frequencies. To configure an electronic knock control system, the exact combination of engine, engine mount, exhaust system, alternator and starter etc. must have been fitted.

A reliable electronic knock control system requires detecting knock accurately and differentiating knock from normal engine noise.

MoTeC's knock modules use the vehicle's original, factory-fitted knock sensors to detect detonation, improving this detection by reducing the influence of background engine noise using a combination of data gating and frequency filtering.

The engine sound energy during engine operation will vary for different frequencies in the spectrum. The knock sound energy will be more prominent at certain frequencies.

A competent tuner needs to carry out a frequency analysis to determine the frequency where the difference of the engine sound with and without detonation is most clear to detect. The centre frequency settings of the Knock Module must match this frequency.

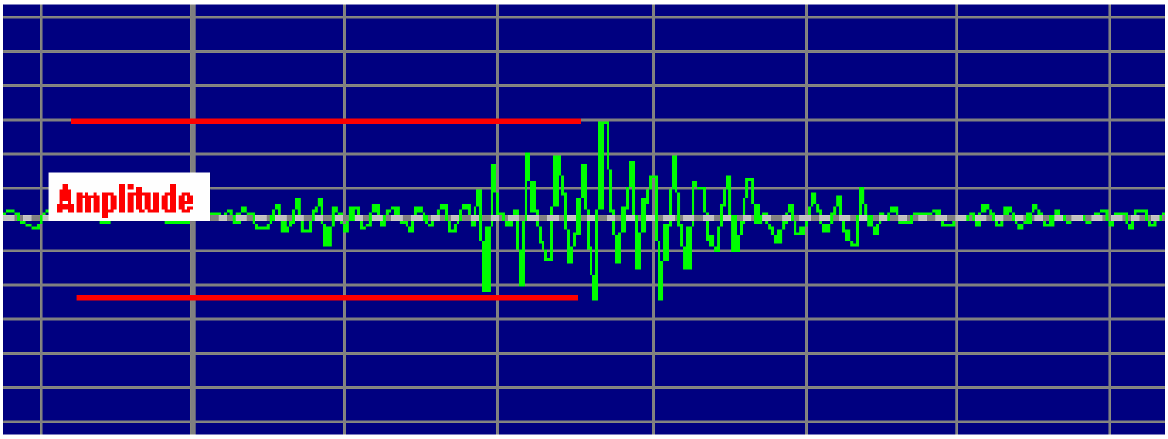
The Knock Control system in the ECU can then be configured to adjust the ignition according to measured knock levels.

Knock Detection

Knock Sensor

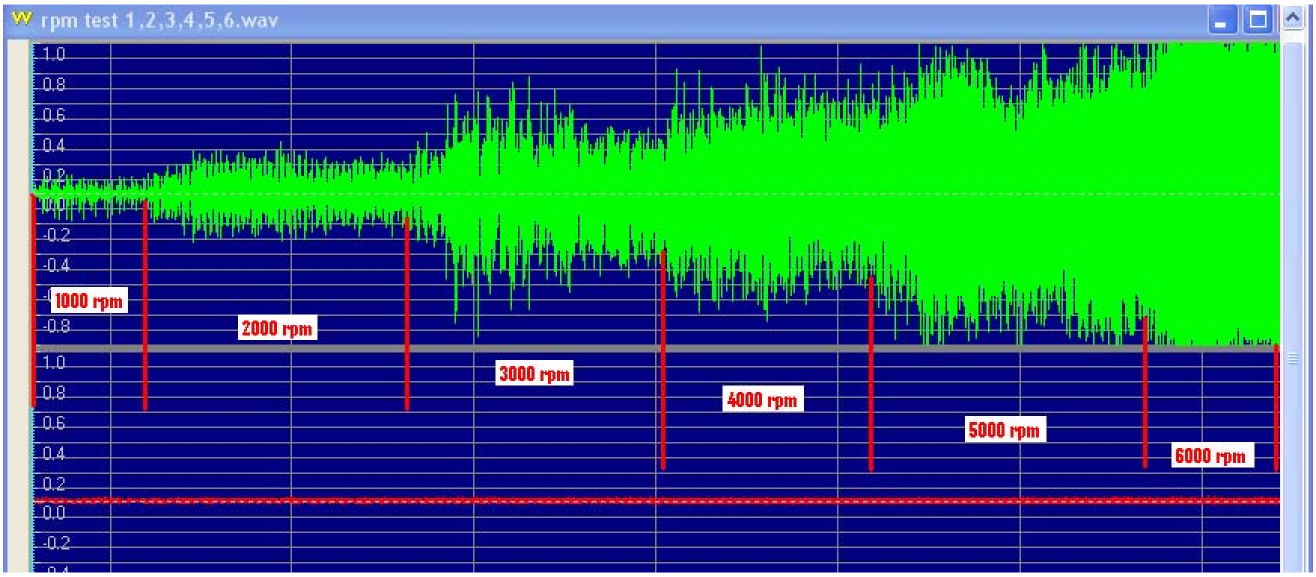
The knock sensor measures the engine vibrations and turns this into an AC waveform output.

The next figure shows a zoomed in view of typical knock sensor signal (captured using Gold Wave Audio Analysis Software www.goldwave.com).



Audio signal output from a knock sensor

With increasing engine RPM, the higher engine vibrations will result in an increase in the amplitude of the knock sensor signal. A race engine operating at high RPM will show high amplitudes making it difficult to detect knock.



Knock sensor signal with increased engine RPM

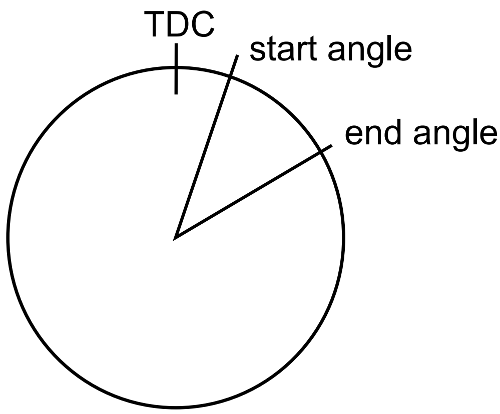
Knock Modules

The SKM/OKM modules improve knock detection by reducing the influence of background engine noise using a combination of data gating and frequency filtering.

Data Gating

The knock window is the period in the combustion cycle during which knock is likely to occur, normally between 10 and 50 degrees after TDC (top dead centre). The ECU sends a knock window signal to the Knock Module to mark the start and end angle in the engine cycle.

The SKM/OKM will measure the knock sensor signal during this window and sends the information to the ECU. The ECU uses the measurement to calculate the knock percentage for each cylinder of the engine.



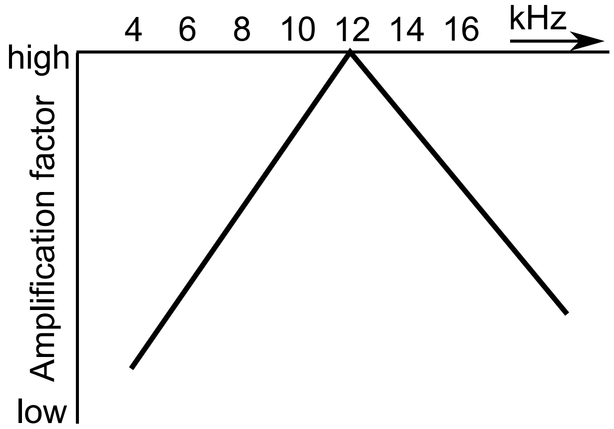
Knock window

Frequency Filtering

To correctly identify knock, the SKM switches must be set to match the theoretical best centre frequency. The centre frequency in the SKM/OKM is normally set to the frequency of the engine that shows the greatest energy difference between normal engine operation and active detonation.

The knock module filters and amplifies the signal transmitted from the knock sensor based on the centre frequency. Signals of the selected centre frequency pass the frequency filter amplified, while signals in other frequencies will be reduced. The further away from the centre frequency, the more the signal will be reduced. Filtering will reduce the influence of background engine noise resulting in improved knock detection.

The figure shows frequency based amplification with the centre frequency set to 12 kHz.



Frequency based amplification

Gain Factor

A gain factor is only required for knock sensors with very low output levels. The gain factor can be chosen to multiply the raw knock output signal, prior to frequency filtering. It is also possible to set a gain factor from ECU Manager software.

Knock Module Configuration

The configuration of the Knock Modules consists of two stages:

Stage 1: Carrying out a frequency analysis of the knock sensor signal to determine the centre frequency and knock module settings. This needs to be done by a competent tuner, as incorrect operation can easily result in severe engine damage

Stage 2: Tuning the knock control system

Note: The OKM settings are preconfigured to suit the standard vehicle. It only requires the second configuration stage to tune the knock system. If the vehicle is modified significantly, contact an authorised MoTeC dealer for further advice.

Before carrying out any stage of the configuration the vehicle needs to be prepared by setting up the ECU for knock measuring and data logging using ECU Manager software.

Preparation

Configuring the Knock Window

- On the **Adjust** menu select **injector/ignition output functions**
- Select **injector/ignition out [#]**
  Select injector or ignition output the SKM//OKM is wired to.
  Note: For M400/M600 Inj8 must be used.
- Select **Function**
- Type Function value 122 (Knock Window)
- Press ESC
- Select **Parameters**

Start Ref

0: knock window measured after ignition point
1: knock window measured after TDC

Typical value 1

Start Angle

The starting angle of the knock window in the engine cycle where the knock sensor signal is recorded

Unit: degrees

Typical value 10

Slow End Angle

The end angle of the knock window in the engine cycle when operating at slow engine RPM (up to 1000 RPM)

Unit: degrees

Typical value 40

Fast End Angle

The end angle of the knock window in the engine cycle when operating at fast engine RPM (RPM as specified in RPM Limit)

Unit: degrees

Typical value 50

Polarity

0: output high for 0% duty
1: output low for 0% duty

Value 0 is required for SKM/OKM

Configuring the channel Knock Voltage

- On the **Adjust** menu click **Sensor Setup**
- Click **Input Setup…**
  this will open the Input Pins Setup screen
- Click the **Other** tab
- Select **Knock Voltage (Knock V)**
- Click **Change**
- In the **Input Source** list click **AV[#]** or **Lambda[#]** (Select the input the SKM//OKM is wired to)
- In the **Calibration** area select **Predefined** and in the list click **#31 Volts(V); x1 (5.000V=5.000V)**

Knock Gain Table

- On the **Adjust** menu click **Functions**
- Click **Knock Control**
- Click **Gain**

This table compensates any sensitivity differences of the sensor to particular cylinders.

The Knock Gain table should be used in conjunction with the Knock Offset table to level out any differences between the individual cylinders.

Typical starting value: 1.00

Note: The values in this table must be non-zero to show any Knock Percentage values.

Data Logging Setup

Each cylinder's knock input should be logged at 50 Hz or greater.

- On the **Adjust** menu click **Data Logging Setup**
- Click **Knock Levels**
- Select **Knock Limit** and type 10
- Select **Knock 1** and type 50 (or greater)
- Continue the last step for all remaining cylinders in firing order

Follow the same procedure to log other useful channels. Recommended channels are:

- Knock Retard Short Term for each cylinder
- Knock Retard Long Term for each cylinder
- Individual Ignition Advance channels - to evaluate the performance of the control system during calibration tuning.

Frequency Analysis

A competent tuner with the right equipment can measure and analyse the knock frequency for the specific engine and associated hardware by comparing the sound of the engine with and without detonation. Frequency analysis will determine the theoretical best centre frequency. This is the frequency where the difference of the engine sound with and without detonation is most clear to detect.

Surprisingly minor changes to the engine hardware will affect the frequency of the detonation “ring” throughout the structure. So frequency settings that suit one car may not be suitable for another car of the identical model but with slight modifications.

Warning

Knock frequency analysis is a specialised job, to be carried out by experienced technicians. Incorrect operation can easily cause severe engine damage.

Setup

1. Using the SKM tuning loom, connect an audio lead to the line in or microphone in port on the PC.
   The PC must be able to record sounds through a line in port and simultaneously play it to the headphone jack, so the operator can listen and monitor the engine while recording.

   Note: If your computer does not have the ability to record and listen at the same time an alternative method should be used to listen to the engine e.g. an external sound card or third party device.
2. Configure the PC to play sound only from the **left** channel. The right channel is the knock window signal sent from the ECU.

   Tip: You can make an adapter plug for the headphones that joins the sound from the left and right channel.
3. Connect audio headphones to the PC.

   Tip: To block out external engine and car noise, bud type ear phones with high quality ear muffs used over top can be used.
4. To perform frequency analysis on the recorded audio file requires dedicated software.
   In this document Gold Wave software is used in all examples.
   See Appendix 4 Gold Wave Settings

Test

1. Ensure the engine is at normal operating temperature.
2. Run the engine and listen for any irregularities in engine vibrations like internal component noise.
3. If all sounds normal bring the engine under some load and carefully introduce light detonation.
   Tip: To introduce detonation at as light a load as possible, use a low octane fuel.
4. Proceed with extreme caution and note where detonation can be introduced. Return to no detonation.
5. Open a new file in Gold Wave and record the data while running the engine from a normal operating situation to a situation with detonation at a similar engine speed.
6. Shut down the engine.

Analysis

1. Configure the Gold Wave Software so that the sound recording can be viewed on a spectrogram (see appendix 4).
2. Play back the Gold Wave audio file.
   The Y-axis on the spectrograms chart is the frequency range, the X-axis is the playback time.
   The colours on the chart represent the energy of the recorded sound. The key to the colours is underneath the X-axis.
3. Look at the spectrogram chart, while listening for detonation. The colour in the spectrogram changes at the moment detonation occurs.
4. The colour change occurs at the knock frequency, but there are often reflections of the detonation at other frequencies.
5. Determine the frequency where the difference of the engine sound with and without detonation is most clear to detect. This will be the centre frequency setting.

Examples

The following examples show how to interpret the data and choose the centre frequency.

Example 1

In the next spectrogram, increased energy levels show consistently at 8 kHz. The noise at this frequency is constant even when the engine is not detonating, therefore we can assume that this is normal engine background noise. Detonation, introduced via an ignition timing adjustment in the ECU, can be seen at the 3.5 second mark. Here extra energy levels are seen throughout all frequencies.

To determine which frequency has the best ratio between little background noise energy and high detonation intensity compare the areas with and without detonation.

In the example, at 5 kHz there is little background noise and a touch of yellow (high energy) at the detonation point. The highest detonation energy is at 8 kHz, however the background noise is also high here.

To help selecting the best centre frequency, experiment with different settings while downloading the log files from the ECU. Analyse the log files using ***i2*** data analysis software.

The log files will show the individual cylinder knock channels. They are represented as a percentage. The absolute value is at this moment not relevant.

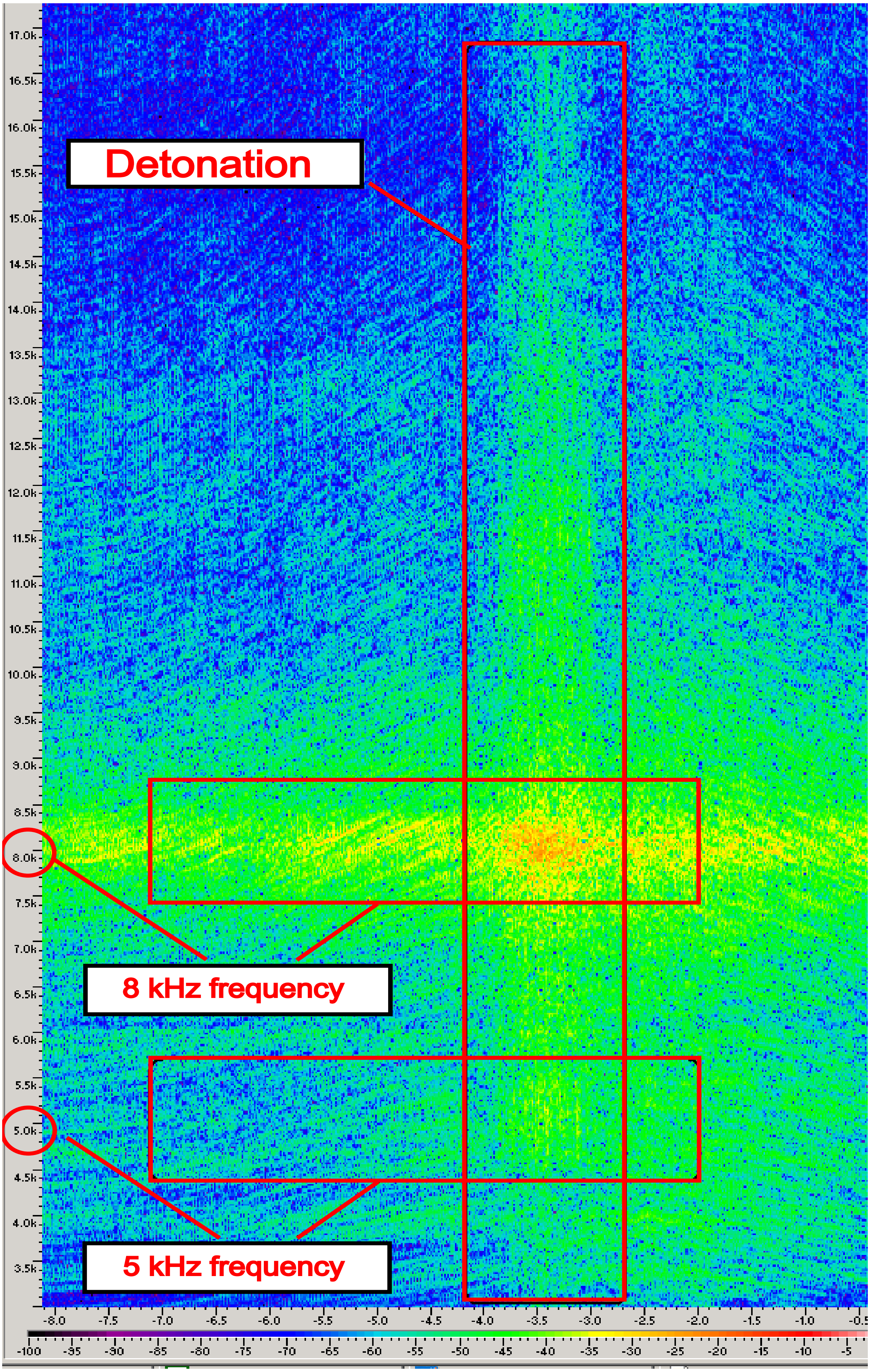
Important is a low background noise level and a high actual knock signal.

The log file with a setting of 8 kHz might equal background noise levels of approximately 60% and mild knock shows peaks of 90%.

A log file with a setting of 5 kHz might equal background noise levels of approx 25% and mild knock showing peaks of 70%.

Therefore a centre frequency setting of 5 kHz would in this example likely be the best.

Note: The centre frequency will affect the overall level of the knock voltage channel.



Frequency spectrogram in GoldWave

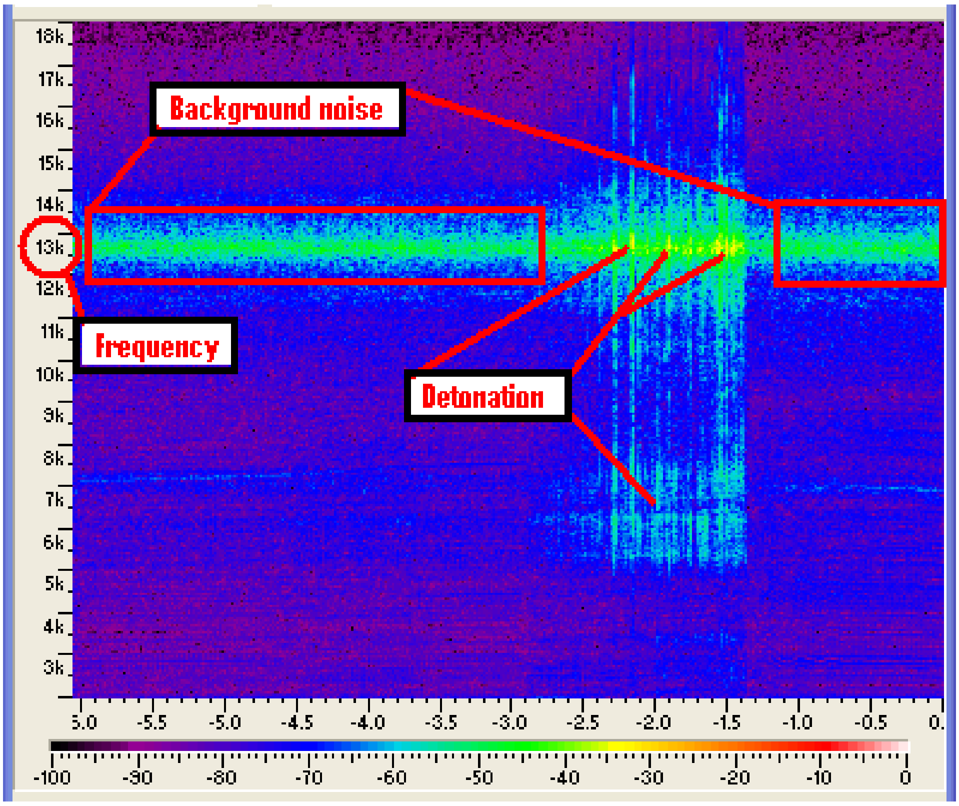
Example 2

The Mitsubishi Evolution Lancer series has a narrowband knock sensor that transmits a signal different to wideband knock sensors.

The voltage amplitude is high compared to signals from wideband sensors for the same level of engine noise, so overall energy levels will be high.

The next spectrogram shows a signal from a narrowband knock sensor. It shows severe detonation at the 2 seconds mark (yellow energy spikes).

The background noise and detonation is concentrated on one frequency, in this case13 kHz.

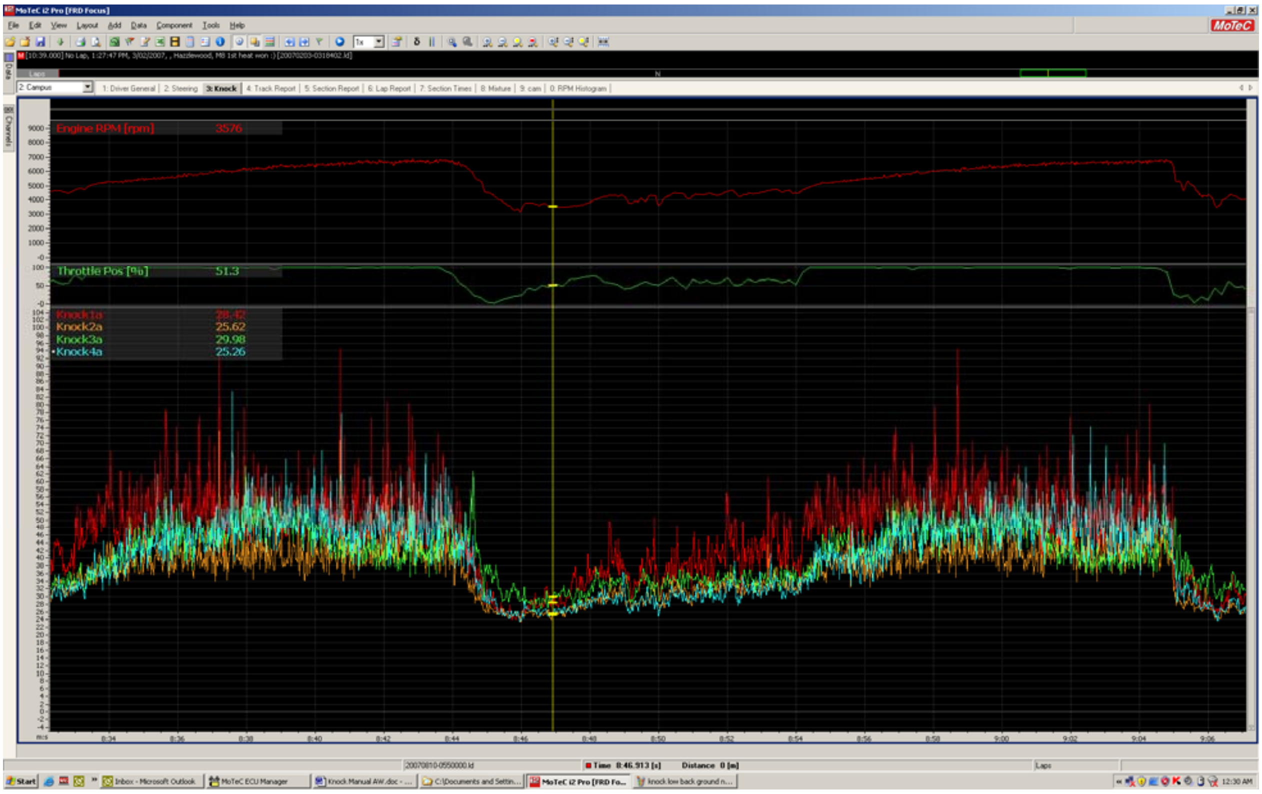


Mitsubishi Evolution Lancer: knock frequency analysis

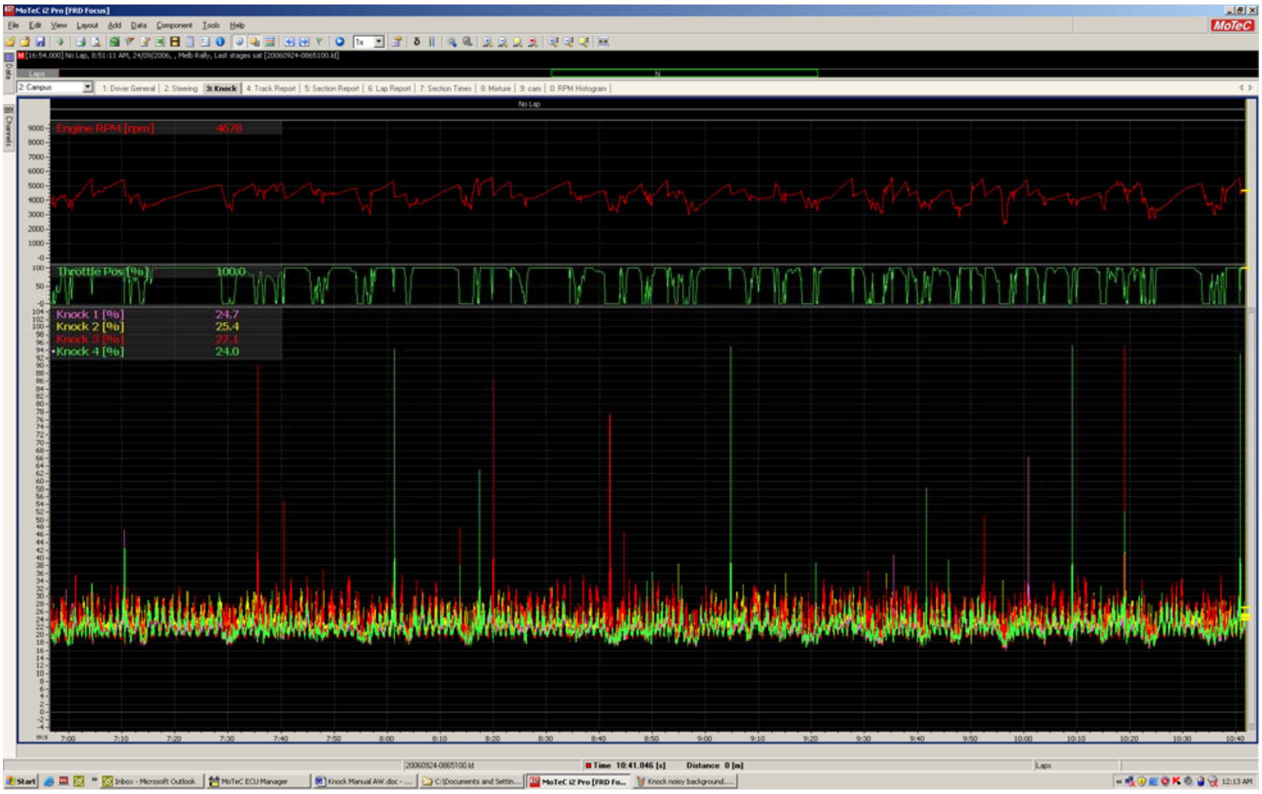
With an example setting of 13 kHz, the log file from the ECU might show background noise level at 50%- 70% and mild knock showing peaks of 90%. This makes it difficult to detect severe detonation, so an SKM/OKM centre frequency setting of 13 kHz would be inappropriate.

The detonation energy is high enough to reflect through other frequencies. For example at 7 kHz, there is less background noise and still relatively high detonation intensity.

With a setting of 7KHZ the log file from the ECU might show background noise level at 30-40% and mild knock at 60%. With this setting larger detonation events can be measured with appropriate action taken as a result. This would therefore be a better choice for the correct setting.



Log file from ECU with a centre frequency setting of 13 kHz



Log file from ECU with a centre frequency setting of 7 kHz

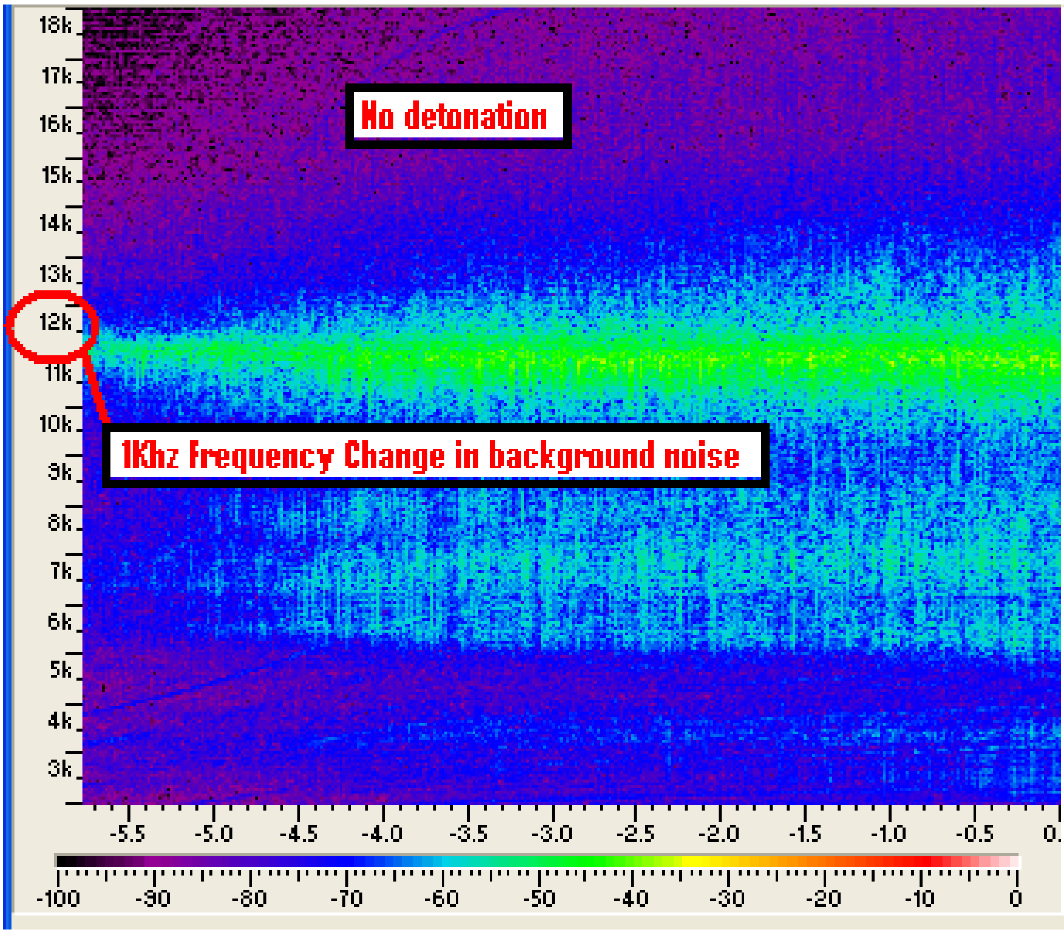
This example highlights the complexity involved in determining knock and appropriate centre frequency settings for each application.

Example 3

The car from the previous example has been converted to rally specifications. This involved fitting a roll cage, larger exhaust etc. Other than a restrictor the engine remains unchanged.

The knock sensor signal is now concentrated on 12 kHz rather than 13 kHz and the characteristics are different.

In this case a centre frequency of 6 kHz may be more appropriate.



Mitsubishi Evolution Lancer rally spec: knock frequency analysis

Centre Frequency Setting

After the knock frequency has been assessed and a centre frequency chosen the Knock Module must be setup accordingly.

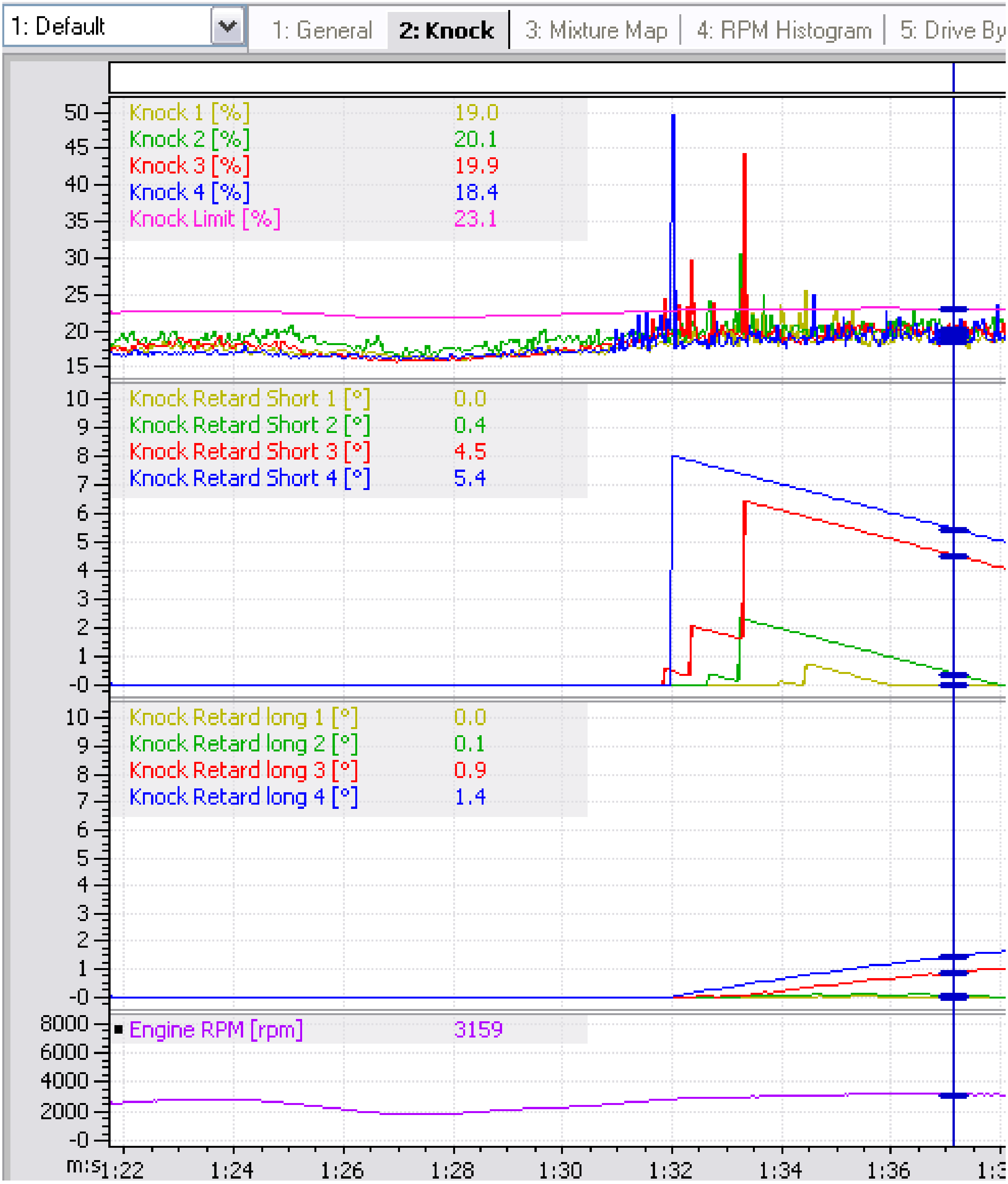
For instructions on changing the SKM switch settings, see appendix 1.

Note: The OKM settings are preconfigured to suit the standard vehicle. However, should adjustment be required because the vehicle is modified significantly, contact an authorised MoTeC dealer for further advice.

Tuning Knock Control System

Note: The following tuning is a specialised job, to be carried out by experienced technicians. Incorrect operation can easily cause severe engine damage.

The knock control system will retard the ignition timing depending on the level of knock. There is an instantaneous setting to reduce the knock levels immediately and a long term retard setting to prevent knock re-occurring.



i2 data showing the instantaneous (short) and long term retard effect on knock levels

The knock control settings are adjusted in ECU Manager software.

- On the **Adjust** menu click **Functions**
- Click **Knock Control**
- Click **Setup** to enter Knock Control and set the following parameters

Activate Throttle Pos

Specifies the throttle position which must be exceeded to activate knock control

0: Disabled - knock control always active

Unit: Percentage (%)

Activate Full Throttle Time

Knock control will only activate when the full throttle timer exceeds this value.

0: Off – Ignore full throttle timer

Units: seconds

Maximum RPM

Knock control is disabled once Engine RPM exceeds this value.

Useful when background noise becomes excessive and clear knock detection is no longer possible.

Normally set to 50 RPM below the RPM limit as engines running on the RPM limit may knock intermittently.

Mode

0: Individual cylinder knock control

1: Global knock control. All cylinders will be retarded equally.

Usually set to 0.
If set to 1 the control system will retard all cylinders, regardless of the cylinder on which the knock was measured.

Error Retard

Specifies the amount of permanent retard that will be applied to all cylinders if the knock sensor goes into error as defined by the diagnostic levels in the input setup.

Unit: Degrees

Warning Trigger

Specifies the level above the Knock Target Threshold (value from Knock Table) which, if exceeded will cause a warning to be generated.

Note: Requires the Driver Warning Alarm function to be configured on an auxiliary output.

Note: The knock warning is included in Status Group 3.

Unit: Percentage (%)

Retard Gain (Instantaneous Term)

Defines the amount of retard applied for each percent over the Knock Target Threshold (value from Knock Table).

Unit: Degrees/Percent

e.g.: Retard gain = 0.5 and knock= 20% over the Knock Target Threshold would result in 10 degrees ignition retard

Advance Rate

Rate at which ignition retard is advanced back to normal.

Unit: Degrees/Second

e.g.: Advance rate = 2 would result in the ignition to advance back at a rate of 2 degrees per second.

Retard Limit

Maximum amount of retard from the current ignition timing (from Ignition Table)

Unit: Degrees

e.g.: Retard Limit = 10 and current ignition timing = 25 degrees BTDC then the Instantaneous term trim aspect of the Knock Control Function can retard to 15 degrees BTDC.

Retard Rate Long term

Amount of long term retard applied per second for each degree of instantaneous term trim retard applied.

Unit: Degrees/Second/Degree

e.g.: Retard Rate Long Term = 0.200 and currently active Instantaneous Term trim = 8 degrees, then 1.6 degrees/second long term trim is also applied.

Advance Rate Long Term

Long term rate at which ignition is advanced back to normal.

Unit: Degrees/Second

e.g.: Advance Rate Long Term = 0.050 would result in the ignition to advance back at a rate of 1 degree in 20 seconds.

Retard Limit Long Term

Maximum amount of long term retard the Knock Control function can remove from the current ignition timing (from Ignition Table)

This is added to the value in Retard Limit for the Instantaneous term trim.

Unit: Degrees

e.g.: Retard Limit = 10, Retard Limit Long Term = 6 and
current ignition timing = 25 degrees BTDC then the Knock Control Function can retard to 25 – (10+6) = 9 degrees.

- When all parameter settings are completed, click ESC
- Click **Knock Table** to enter the Knock Table window

This table sets the Knock Target Threshold (or Knock Limit) for the Knock Control function.

The ignition will not be retarded unless the measured knock value of any of the cylinders exceeds the Knock Target Threshold value.

To determine Knock Target Threshold values, run the engine in a non knocking condition with safe ignition timing. Operate the engine fully loaded through all RPM levels and note the background noise levels in the cylinders knock percentage channels.

The Knock Table is configured with RPM as X-axis. As a starting point, values are to be entered at 5 to 10% above background noise levels.

- When all Knock Table settings are completed, click ESC
- Click **Gain** to enter the Knock Gain Table

This table compensates any sensitivity difference of the sensor to particular cylinders.

The Knock Gain table should be used in conjunction with the Knock Offset table to level out any differences between the individual cylinders.

Typical starting value: 1.00

Note: The values in this table must be non-zero to show any Knock Percentage values.

- When all Gain settings are completed, click ESC
- Click **Offset** to enter the Knock Offset Table

This table compensates for any offset differences of the sensor to particular cylinders.

The Knock Offset table should be used in conjunction with the Knock Gain table to level out any differences between the individual cylinders.

Typical starting value: 0

Knock Tuning Tips

- Set both Retard Limit and Retard Limit Long Term to 0 degrees.
- Listen for detonation while running the engine.
- Introduce light detonation very carefully and log the knock percentages.
- Estimate the Ignition Retard required preventing this level of knock continuing.
- Adjust the Instantaneous Term trim parameters:
  Start with values which will cause too much retard.
  Work your way back until an appropriate strategy for the type of engine is found.
- To start, work with Instantaneous Term trim only
- Add the Long Term trim parameters later if required.

Operation

Once the Knock Control System is tuned, it can be used for continuous monitoring.

The configuration will generally not need any adjustment. Only major changes in engine (exhaust, cams, pistons etc) and transmission might require a new centre frequency setting.

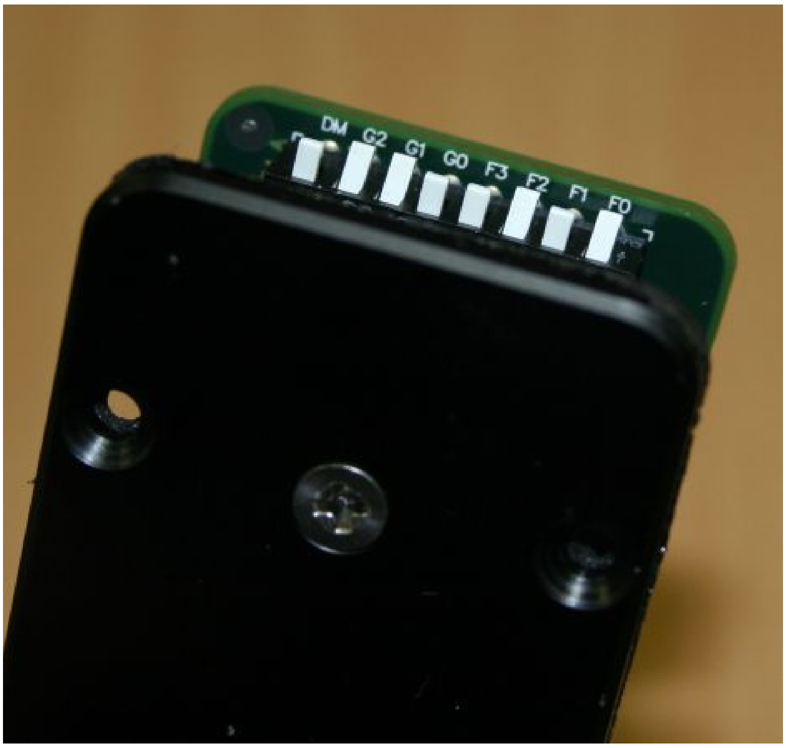
In this case, the vehicle should be returned to the dealer for a new frequency analysis.

Appendices

Appendix 1 SKM Internal Dip Switch Settings

Dip switches are used to set the gain factor, centre frequency and the differential mode switch.

To access the switches, remove the 4 lid locating screws. Hold the device as shown in the photo to see the various switch identification codes.



SKM Dip Switches

Switch down toward the circuit board = on
Switch up away from circuit board = off

Differential Mode Switch

DM	Function
off	normal knock sensor connection (default)
on	differential sensors

Gain Switches

G2	G1	G0	Gain
On	on	on	2 (default)
On	on	off	4
On	off	on	8
On	off	off	16
Off	on	on	16
off	on	off	32
off	off	on	64
off	off	off	128

Knock Centre Frequency Switches

F3	F2	F1	F0	Frequency
off	on	on	on	5 kHz
off	on	off	on	6 kHz
off	on	off	off	7 kHz
off	off	on	on	8 kHz
on	off	off	on	9 kHz
on	on	on	on	10 kHz (default)
on	on	off	on	12 kHz
on	on	off	off	14 kHz
on	off	on	on	16 kHz

Appendix 2 SKM Connector, Pin Out and Wiring

Connector Autosport 13 pin Mating connector #65041			
SKM		**Connect to**	
Pin	**Function**	**Device/connector**	**Input**
1	Select 0		
2	Select 1		
3	Knock ECU Out	M400/M600/M800/M800	any available AV input, preferable a Lambda sense input
4	Knock Audio Out	3.5 mm stereo connector	tip (left channel)
5	Audio Ground	3.5 mm stereo connector	ring (ground)
6	Sensor 1 Input	knock sensor	signal
7	Sensor 2 Input		
8	Sensor 3 Input		
9	Sensor 4 Input		
10	Shield	knock sensor	shield
11	Knock Window	M400/M600	injector8 only
		M800/M880	any spare ignition or injector output
		3.5 mm stereo connector	via 100 KΩ resistor to ring (right channel)
12	8 V	M400/M600/M800/M880	8 V
13	Ground	M400/M600/M800/M880	ground

Appendix 3 SKM Tuning Loom #61114

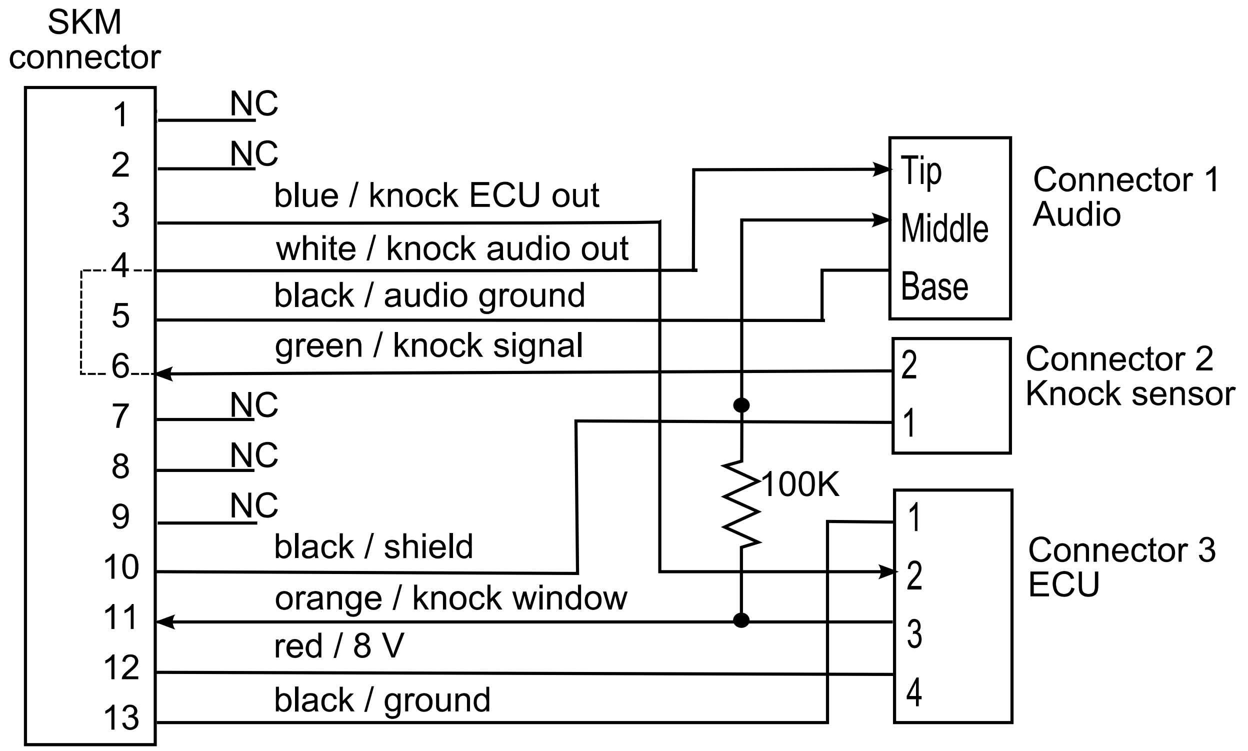
Optionally the SKM Tuning Loom can be used for wiring.

- Length of the ECU and knock sensor leads is 600 mm
- Length of the audio lead is 1850 mm

Connector 1: Stereo plug		
Pin	**Function**	Connect to stereo headphones
Base	Audio Ground	
Middle right channel	Knock Window	
Tip left channel	Knock Audio Out	

Connector 2: DTM 2 pin Mating connector #68051		
Pin	**Function**	**Connect to knock sensor**
1	Shield	Shield
2	Knock Signal	Signal

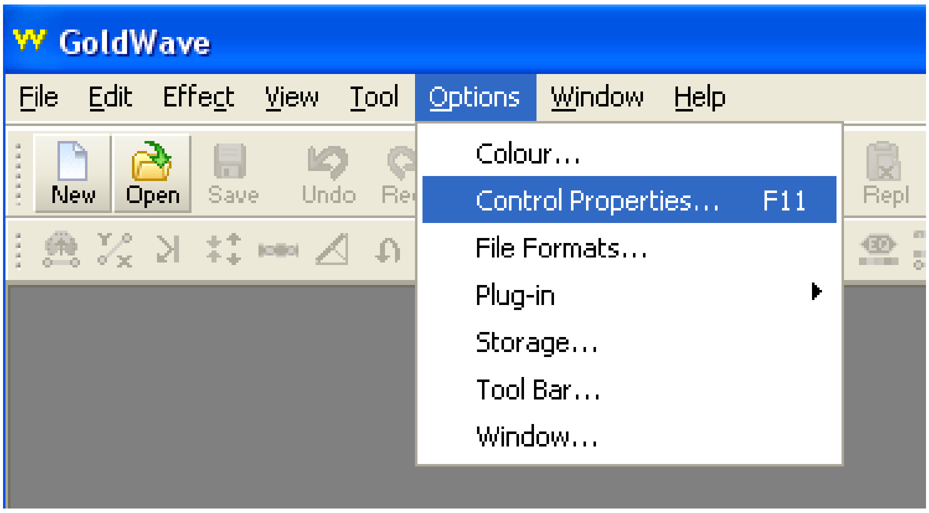
Connector 3: DTM 4 pin Mating connector #68054		
Pin	**Function**	**Connect to M400/M600/M800/M880**
1	Ground	Ground
2	Knock ECU Out	Any available AV input, preferable a Lambda sense input
3	Knock Window	Any spare ignition or injector output Note: on M400/M600 injector8 only
4	8 V	8 V


SKM
connector
1
2
3
4
5
6
7
8
9
10
11
12
13
NC
NC
blue / knock ECU out
white / knock audio out
black / audio ground
green / knock signal
NC
NC
NC
black / shield
orange / knock window
red / 8 V
black / ground
100K
Tip
Middle
Base
Connector 1
Audio
2
1
Connector 2
Knock sensor
1
2
3
4
Connector 3
ECU

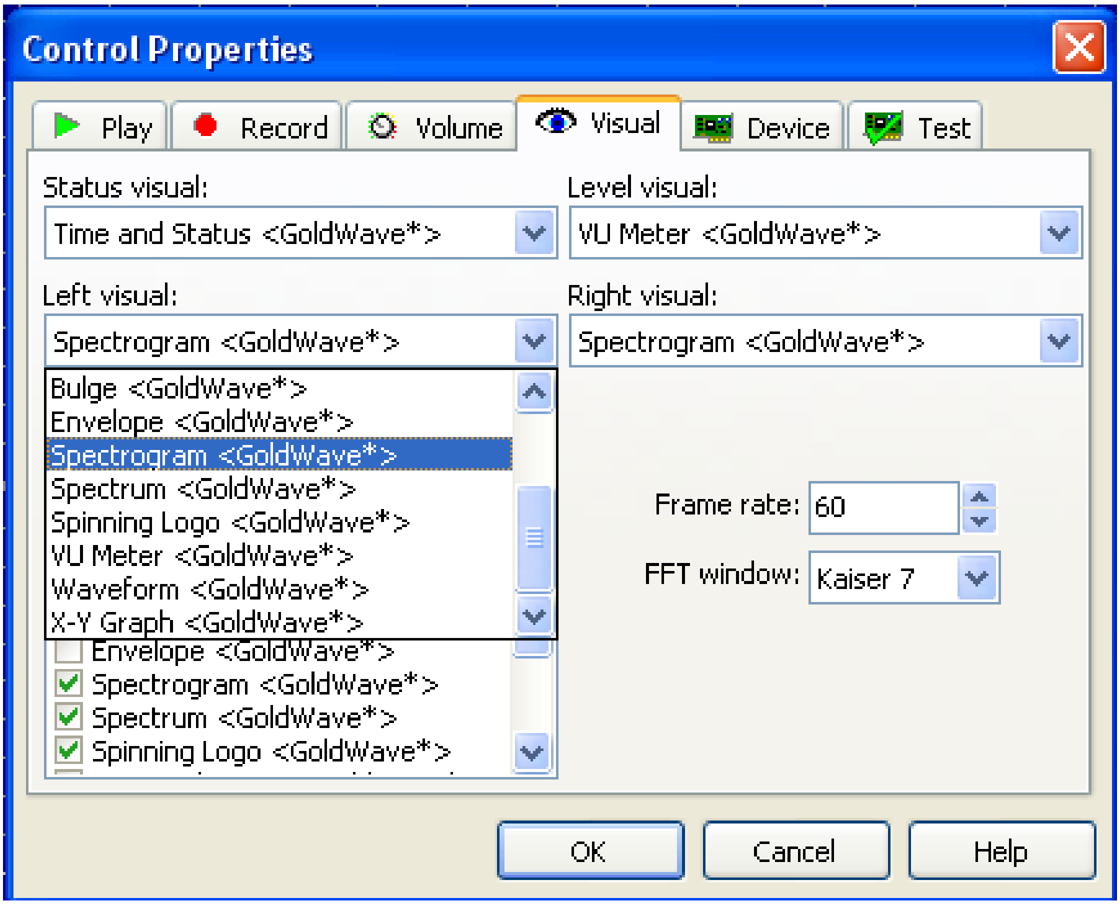
Appendix 4 Gold Wave Settings

To set up the side display as a Spectrogram for analysing frequency of sounds:

On the **Options** menu click **Control Properties** (keyboard shortcut F11)



In the **Left Visual** box, select *Spectrogram <GoldWave*>*



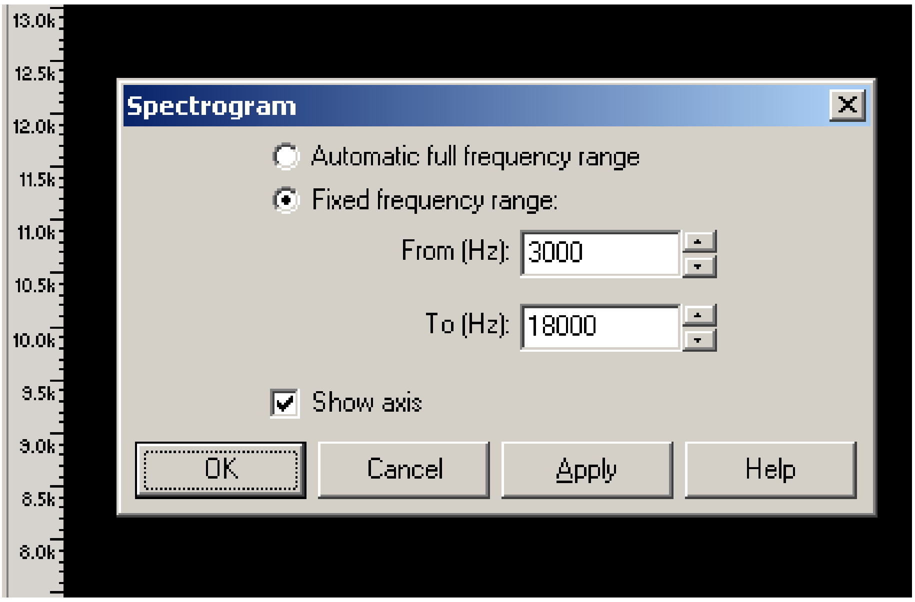
On the **Tool** menu click **Control**

Right click in the screen to open the menu and select **Spectrogram <GoldWave*>**

Click **Properties** to configure the spectrogram.

Choose **Fixed frequency range** and set range to **From (Hz) 3000 To (Hz) 18000**

Choose **Show Axis**



Appendix 5 Detonation Explained

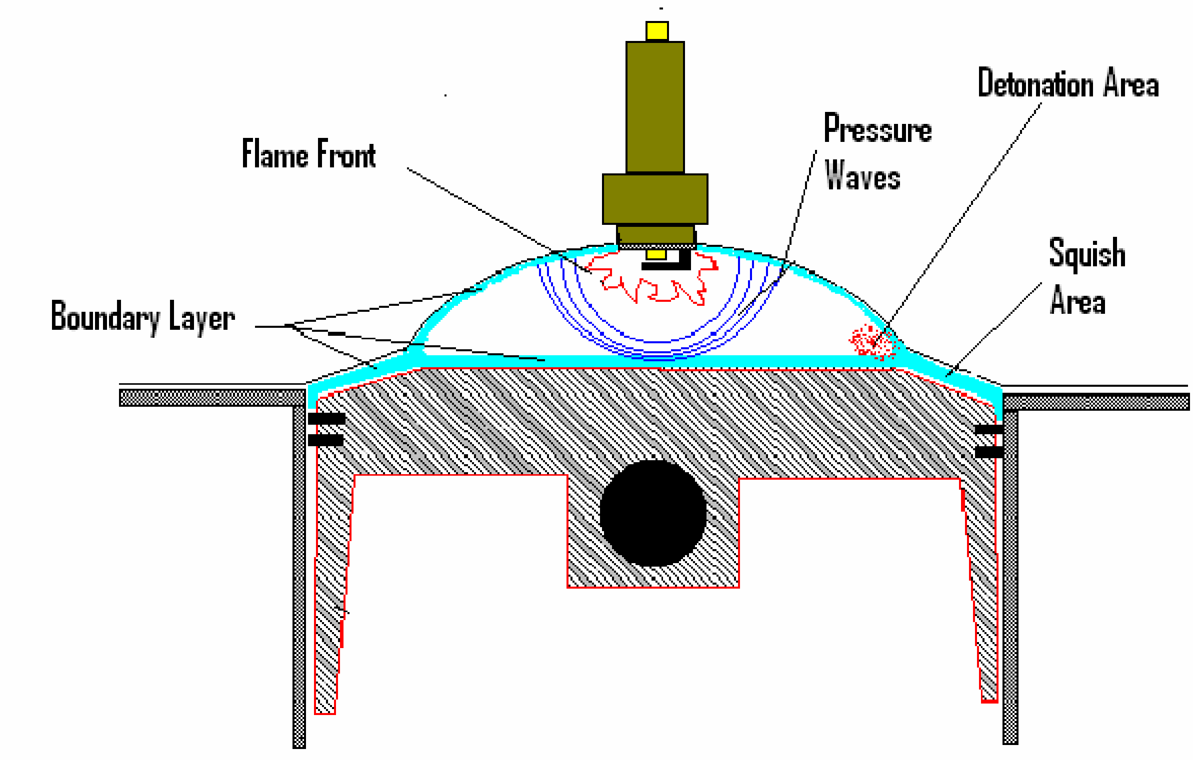
Detonation (also called "spark knock") is an erratic form of combustion that can cause catastrophic engine failure. Detonation occurs when excessive heat and pressure in the combustion chamber causes the air/fuel mixture to self ignite. This produces a sudden rise in cylinder pressure accompanied by a sharp metallic pinging or knocking noise. The hammer-like shock waves created by detonation subject the head gasket, piston, rings, spark plug and rod bearings to severe overloading. Mild or occasional detonation can occur in almost any engine and normally causes no harm. But prolonged or heavy detonation can be very damaging.

Detonation is the result of an amplification of pressure waves, such as sound waves, occurring during the combustion process when the piston is near top dead centre (TDC). The actual "knocking" or "ringing" sound of detonation is due to pressure waves pounding against the insides of the combustion chamber and the piston top. It is not due to 'colliding flame fronts' or 'flame fronts hitting the piston or combustion chamber walls.'

Normal Combustion

This is the burning of a fuel and air mixture charge in the combustion chamber. It should burn in a steady, even fashion across the chamber, originating at the spark plug and progressing across the chamber in a three dimensional fashion. Similar to the ripples spreading out when a pebble is thrown into a pond with a glass smooth surface, the flame front should progress in an orderly fashion. The burn moves all the way across the chamber and quenches (i.e.: cools) against the walls and the piston crown. The burn should be complete with no, or very little, remaining unburnt fuel-air mixture. Note that the mixture does not "explode" but burns in an orderly fashion.

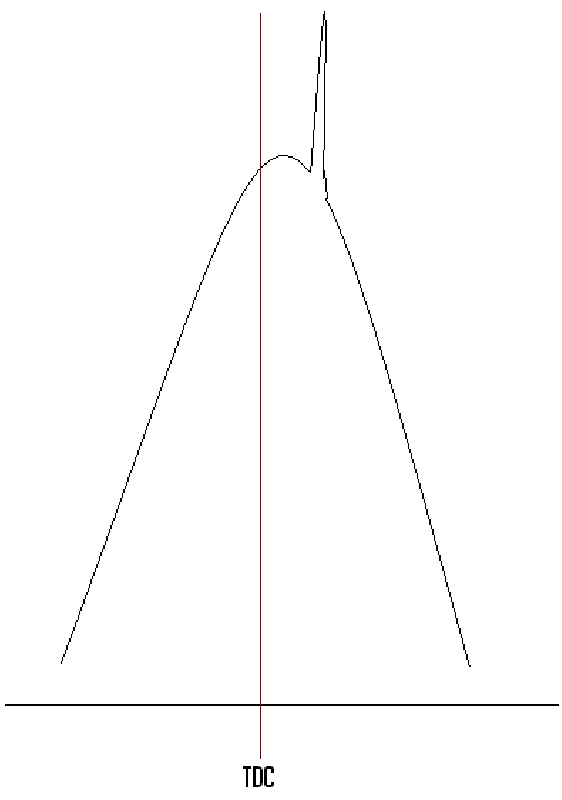
During combustion, the location of peak pressure (LPP) can be measured with an in-cylinder pressure transducer. When the spark is fired at optimum timing the burn is initiated at the spark plug and will progress evenly through the chamber to reach peak pressure shortly after top dead centre depending on the chamber design and the burn rate. Ideally, the LPP should occur between 12 and 15 degrees after top dead centre.



Combustion chamber at TDC

Abnormal Combustion – Detonation

If conditions for combustion are not ideal, detonation can occur. This usually happens first at points of amplification of the pressure waves.



Combustion Pressure with detonation

For example at the edges of the piston crown where reflecting pressure waves from the piston or combustion chamber walls can constructively recombine – this causes very high local pressures. If the speed at which this pressure build-up to detonation occurs is greater than the speed at which the mixture burns, the pressure waves from both the initial ignition at the spark plug and the pressure waves coming from the problem spots can set off immediate explosions in the remaining air/fuel mixture, rather than smooth combustion. The remaining fuel in the end gas simply lacks sufficient octane rating to withstand this combination of heat and pressure.

Detonation causes a very large, very rapid, pressure spike of very short duration in the combustion chamber. The pressure trace of the combustion chamber process would show the normal burn as a steady pressure rise, and then all of a sudden a very sharp spike when the detonation occurred. The pressure spike creates a force on the combustion chamber causing the structure of the engine to ring or resonate (much as if it were hit by a hammer). Resonance, which is characteristic of combustion detonation, occurs between 4 to 12 kHz resulting in the audible pinging. This noise or vibration is what the knock sensor detects.

Detonation Indicators

The best indication of detonation is the pinging sound that cars, particularly old models (pre 1980) make at low speeds and under load. It is very difficult to hear the sound in the well insulated luxury interiors of today's cars. An unmuffled engine running straight pipes or a Rally Car racing on a gravel road can easily mask the sound.

In some cases, the engine may smoke but more often the driver is not aware detonation is occurring.

Typical results of detonation are broken piston ring lands, broken spark plug porcelains or broken ground electrodes. However these signs are usually not spotted externally.

It is also difficult to detect detonation while an engine is running in a remote and insulated dyno test cell.

To help hear detonation a very elementary technique often proves successful: run a copper pipe bolted flat to the side of the engine block into the control room, place a funnel at the end to amplify the sound through the pipe and listen. This allows the operator to hear all mechanical noises within the engine and helps to identify detonation should it occur.

Also commonly used for knock detection are electronic amplifiers.
These devices either connect directly to a knock sensor or use an alligator clip placed on the engine block. The engine sounds are amplified and filtered and then routed to the operator via headphones.

Detonation Failures

Detonation causes three main types of failure:

1. Mechanical damage (broken ring lands, hammered big end bearings)
   The high impact nature of the pressure spike can also cause fractures; it can break the spark plug electrodes, the porcelain around the plug, cause a clean fracture of the ring land and in severe cases can actually cause fracture of valves-intake or exhaust.
2. Abrasion (pitting of the piston crown).
   The sandblasted appearance to the top of the piston near the perimeter the piston is typical if detonation occurs. Examined with a

microscope the small holes are not unlike those found in Swiss cheese. The detonation actually mechanically erodes material out of the piston. Typically the sandblasted look can be expected in the part of the chamber most distant from the spark plug.

3. Overheating (scuffed piston skirts due to excess heat input or high coolant temperatures).
   Because the pressure spike is very severe and of very short duration, it can actually shock away the boundary layer of gas that surrounds the piston. Normal combustion temperatures exceed 900 deg Celsius. An aluminium piston, subjected directly to that temperature, would melt.
   Under normal combustion it does not melt because of its thermal inertia and because of a boundary layer of air fuel mixture a few molecules thick next to the piston top. This thin layer isolates the piston from the flame and causes the flame to be quenched as it approaches this relatively cold material. This protects the piston and chamber from absorbing the heat of the combustion.

   However, under extreme conditions the shock wave from the detonation spike can cause the boundary layer to breakdown. Since pressure waves created during detonation can sweep away these unburned boundary layers of air-fuel mixture they leave parts of the piston top and combustion chamber exposed to the flame front. This, in turn, causes an immediate rise in the temperature of these parts, often leading to direct failure or at least to engine overheating.

Detonation Causes

The potential for detonation is influenced by chamber design elements including: shape, size, geometry, plug location, compression ratio, engine timing, mixture temperature, cylinder pressure and fuel octane rating. Too much spark advance ignites the mixture too soon, increasing the pressure resulting in spontaneously combustion.

Preventing Detonation

With the engine configuration set, detonation can be reduced by

- reducing ignition timing
- reducing air/fuel intake temperature (i.e. making the mixture richer or using a larger intercooler)
- Reducing Coolant Temperature
- Using a fuel with a higher octane rating