Remi System Overview

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Revision History

The following table shows the revision history of this document.

Date	Description
Apr 2019	Initial document.
December 2021	First public release.

Contents

1 Introduction

Remi is a modern electronic system specially dedicated to aircraft engines. It combines two ECUs modules, electrical power module and engine monitoring system into one physical unit. This greatly simplifies overall complexity of engine electronics, adds redundancy and safety, adds power and reduces fuel consumption, directly communicates with other avionics, supports external, non-engine related sensors and allows for future extensions.

The purpose of this document is to give some insights about Remi's system basic blocks and main working principles. It also allows visualization of the parallelism which significantly adds to overal safety of the system.

1.1 System Elements

Figure 1 illustrates main system elements and interactions between them. These elements are:

`Remi` is the innovative electronics module.

`Engine core` is the aircraft engine itself with its essential subsystems. Turbo unit, propeller controller and governor are not part of the core.

`Avionics` are aircraft instruments used to display the engine status and information and to interact with a pilot.

`External sensors` are non-engine related sensors, not required by the engine, but otherwise important for the aircraft operation.

`Engine additions` are engine and power-train related extensions.

`Pilot` has the overall control over the system.

1.2 Interactions

Figure 1 also defines various interactions between the elements. Interactions are shown with arrows. The main purpose of this document is to describe the interactions in detail. First short overview is provided and more details follow in separate sections.

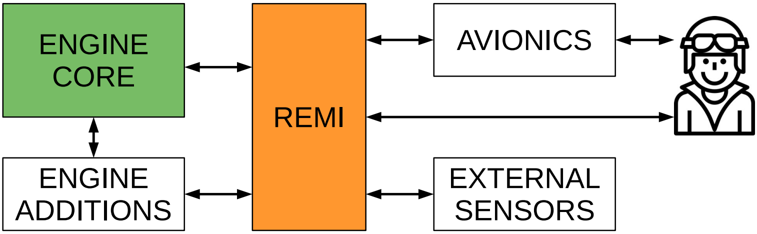

Figure 1: Interactions between Remi and engine.

1.2.1 Remi – Engine Core

Interaction between Remi and engine is the most complex one. Figure 2 identifies engine and Remi subsystems.

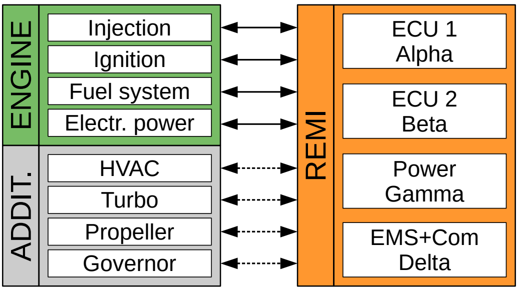

Figure 2: Interaction between Remi and main elements.

From Remi's perspective, an engine consists of the following subsystems: injection, ignition, fuel system and electrical power system. There are more subsystems like cooling and lubrication, but the interaction with Remi here is simpler, hence they are omitted.

Remi consists of four subsystems (hereinafter referred to as modules): ECU 1 is the main ECU (alpha module), ECU 2 is the backup ECU (beta module), Power (gamma module) serves as a regulator and backup power controller and EMS+Com (delat module) provides communication to the outside world (avionics) and external sensors support. All these modules are part of one "black box".

Injection subsystem has two independent injection systems and interacts with several Remi modules, mainly with ECU 1 and ECU 2. Details are given in section 3.

Ignition subsystem mainly interacts with ECU 1 and ECU 2. Details are given in section 4.

Fuel system provides fuel for each injection system and involves electrical fuel pumps regulation. It interacts with ECU 1 and ECU 2. See section 2 for more details.

A running engine is also a source of AC electrical power. This power is needed to run all engine electronics and other electrical devices on the aircraft. Section 6 revails how Remi's power module takes care for this power distribution.

1.2.2 Remi – Engine Additions

The grey area of Figure 2 shows some engine related additions like: HVAC (engine air conditioning), variable pitch propeller, turbo unit and throttle governor. Support for these possible extensions are planned for future Remi versions.

- Remi will support cowling flap controller. This will allow automatic air conditioning of the engine. Cowling flaps will be automatically adjusted to keep the engine in optimal working temperature and to prevent rapid change of engine temperature.
- Remi will support turbo system. It will act as a turbo controller unit by regulating the waste gate valve.
- Remi will act as propeller controller and it will automatically adjust propeller pitch to get optimal propeller RPMs. Support for hydraulic and electric variable pitch propellers is planned.
- Throttle governor for small helicopters is planned too. A change of collective lever position must be compensated with change of throttle. Remi will allow automation of throttle adjustment.

1.2.3 Remi – External Sensors

Engine is equipped with many different sensors. Some of them are essential for the engine operation and some of them are informative. MAP and crankshaft positions sensors are example of essential sensors. Electronics based engine can't operate without them. Coolant temperature sensor is not essential (engine can operate without it), but informative as it can tell pilot that engine is not working in optimal conditions.

In addition to the engine related sensors mentioned above, Remi supports connection of various aircraft sensors that are not necessarily engine related. For example, helicopter rotor RPM sensor, rotor gearbox pressure, rotor gearbox temperature, fuel level, trim positions, etc.

Remi delta module will take care for these additional sensors. The same principles as they are used in our Daqu EMS box apply here as well. Remi will provide digital (Y channels) and analogue channels (A, C, E and F type) for optimal external sensor support.

The following channels are available:

- 2 x A channel for resistive sensors and J and K type thermocouples.
- 2 x E channel for 0–5V input and resistive fuel level sensors.
- 2 x F channel, which is the same as E, but supports also sensors with 4-20 mA current output.
- 2 x Y channel for sensors with digital signal output (rectangular signal shape).
- 1 x C channel for voltages up to 40V.

A detailed information can be obtained from Daqu 2.3 and Mini Daqu manual, where connection principles, supported sensors and channel types are documented. Remi's delta module builds upon this.

1.2.4 Remi – Avionics

Figure 2 shows strong dependency between the engine subsystems and internal Remi modules. A lot of information is passed between the modules and engine subsystems. In addition to this, a lot of information is also received from external sensors.

Figure 3 shows communication principle between Remi and other aircraft avionics. Two independent CAN bus networks are used: internal bus and avionics bus. The internal bus connects all Remi modules and is not accessible from the outside. The Delta modules then collects the relevant information from the internal bus, adds information from external sensors and re-transmits the information on the avionics bus. Avionics interprets the information and shows it on screens.

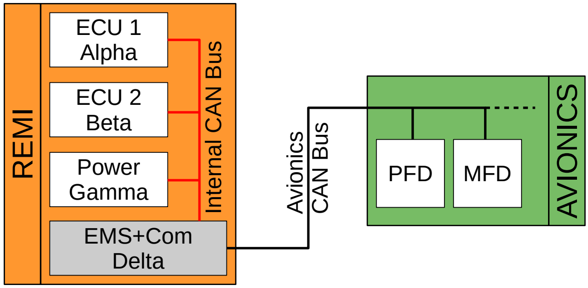

Figure 3: Interaction between Remi and Avionics.

It is possible for avionics to send some information to Remi as well. The delta module intercepts it, filter it and only when it is relevant copies it to the internal bus.

Having two independent buses is a safety feature. Failure of the avionics bus does not affect internal CAN bus at all. Remi does not need avionics bus for the normal operation.

1.2.5 Remi – Pilot – Avionics

Although Remi has a high level of independence, it is the pilot, who has the ultimate control over the Remi system. Figure 1 in page 8 shows that interaction is direct and indirect.

Aircraft avionics represents the indirect way. The information from Remi is transmitted on avionics bus and various avionics instrument show its content. Pilot reads this and reacts accordingly.

Pilot can also pass the some information via avionics. Avionics usually have some means of input and this can be used to send commands to Remi.

In any case, the primary way of Pilot – Remi interaction is the direct one. In this case Pilot can issue the following commands:

- Start the engine.
- Stop the engine.
- Put Remi into automatic mode.
- Select ECU 1 as the main ECU.

- Select ECU 2 as the main ECU.

This can be achieved with two alternatives. Both are commonly used in small aircraft, so pilots are already familiar with the usage.

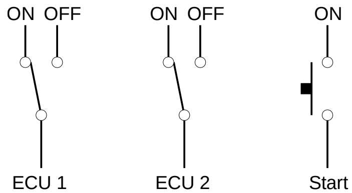

Figure 4: Pilot operation with two SPST switches and a push button.

Figure 4 illustrates the first solution. The solution uses two SPST switches and one normally open push button. The first SPST controls ECU 1 and the second ECU 2. Push button is used to start the engine. When both switches are off, both ECUs are off and engine is not operating. When only ECU 1 switch is on, Remi operates on ECU 1 only. When only ECU 2 switch is on, Remi operates ECU 2 only. When both switches are on, Remi operates both ECU in parallel in automatic mode. The push button is used to start the engine. Engine start procedure is automatic. At least one ECU must be on, for the engine to start.

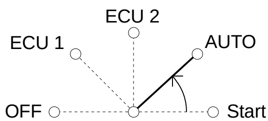

Figure 5: Pilot operation with four pole switch and fifth push pole.

Figure 5 illustrates the second solution. This uses one rotational five pole switch, where the fifth pole has a spring, which pushes back to forth pole.

When selector points to OFF, both ECUs are off and engine is not running. When selector points to ECU 1, only ECU 1 is on. When selector points to ECU 2 only ECU 2 is on. When selector points to AUTO, both ECUs are on and they are running in automatic mode. When selector points to Start, both ECUs are running and Remi engages the starting sequence.

Normal Remi operation requires both ECUs to run in parallel. Single ECU selection is used only in checks and in emergency situations.

2 Fuel System

This section describes Remi's fuel system mechanics. The goal of the fuel system is to provide the fuel for injectors in adequate quantity and at correct pressure.

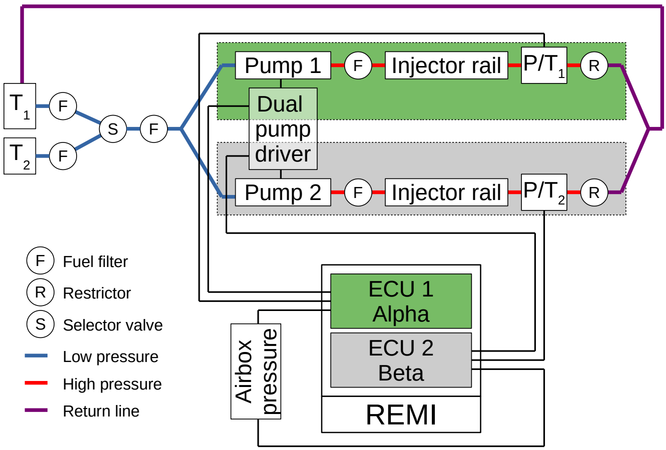

Figure 6: Fuel pressure schematics and connections with Remi.

Figure 6 illustrates relations between fuel system and Remi. The fuel system can be divided into three parts: low pressure part from tank to the fuel pumps, high pressure part which supplies fuel to injectors and low pressure return line, which returns fuel back to the tank.

2.1 Low Pressure

The low pressure part of the fuel systems starts in the fuel tanks. Let's assume typical system with two tanks, which is very common in practice.

Exit of each tank shall be equipped with the a coarse particle filter. Fuel line from tank then enters the fuel selector. The fuel selector is used to switch between fuel tanks, where one, other or both tanks can be selected for the operation. Fuel can be also completely closed. Another fuel filter is usually applied after fuel selector.

The complete low pressure part of the fuel system is aircraft specific and is not really releated to the engine selection. Remi system does not alter this part.

Contrary to the automotive solutions, small aircraft almost never use submerged fuel pumps and fuel pumps are mounted on the engine side of the firewall (or very close to the firewall). This means that low pressure part can be also in suction and as such subject to vapor lock effect.

2.2 High Pressure

After selector, low pressure fuel line crosses firewall and splits into two independent branches. One branch is controlled by ECU 1 and the other by ECU 2.

Each branch has a high pressure fuel pump followed by a fine particle filter, which prevents dirt entering injector nozzles. From the filter the fuel line enters injector rail, which distributes fuel to individual injectors. At the end of the injector rail is a fuel pressure and a temperature sensor. At the very end of each high pressure branch is a restrictor, which limits the flow terminates the high pressure area. We do not use pressure regulator.

2.2.1 Pressure Regulation

As can be seen from Figure 6, pressure regulator elements are not used. Active regulation of fuel pumps is used instead. At the start of each high pressure line is a fuel pump and at the end is a fuel pressure sensor. Another pressure sensor in located in the airbox. Remi ECU module reads both sensors and regulates fuel pump to maintain the constant pressure across the injectors. PWM regulation is used. Remi ECU module sends PWM signal to the fuel pump driver, which amplifies the signal and drives pumps.

The principle of operation is identical for both high pressure fuel line branches. Each high pressure fuel line has its own set of sensors, which are connected to the corresponding ECU. The sensors in airbox are also duplicated.

For the sake of simplicity, only one physical fuel pump driver is used. But this driver has two completely independent channels and failure of one channel does not affect the other and it can be viewed as two separated pump drivers. The driver has double power leads.

2.2.2 Restrictors And Vapor Lock

We decided to use restrictor at the end of fuel line and fuel return back to the tank. Normally, such solution is not necessary if fuel pumps are regulated from ECU to maintain the correct pressure. But as significant part of fuel line is in low pressure area, maybe also in suction, fuel pumps are often mounted in engine compartment and as engine ambient pressure can change very quickly, vapor lock effect can't be ignored. To mitigate the vapor lock problem, the restrictors are used. They allow fuel flow to circulate. As fuel keeps circulating, fuel does not collect so much heat and any fuel vapor that may build up has chance to escape back to fuel tank trough the return line.

The restrictors must be highest points of the fuel line – to allow any fuel vapor to enter back to fuel tank, where it will condensate back to liquid form.

The fuel pressure sensor is also a temperature sensor and it measures the fuel temperature on the exit to return line. This temperature also acts as a safety measure against vapor lock.

2.3 Return Line

When fuel exits the restrictor, high pressure area ends. Exits from both high pressure branches are connected together and returned back to the tank. Here fuel cools downs and any vapor, when present, condensates.

Different aircraft use different solution for the returning fuel. The most common solution is to return fuel to the same tank. This does not present drawback as long as this tank is always used first.

Some complex fuel selector valves allow fuel return to the source tank. In this case, fuel return line is connected with the selector. The return fuel travels back to selector and from there the active tank.

2.4 Electrical Connections

Remi requires two independent pressure fuel lines (two branches). One is controlled by ECU 1 and the other by ECU 2. Pumps are controlled indirectly by a driver.

ECU 1 (alpha module) connects to fuel pressure and temperature sensor on branch 1. At the same time, it also connects to pressure and temperature sensor in the airbox. According to the sensor readings it calculates the PWM signal, which is transmitted to the channel 1 of the fuel pump driver. The channel then provides high current PWM directly to the pump 1.

The same is true for the ECU 2 and the second high pressure branch: fuel pressure and temperature sensors on branch 2 are connected directly to ECU 2 together with the second airbox pressure and temperature sensor pair. The

PWM signal is sent to the channel 2 of the fuel pump driver. Driver then provides high current PWM to the pump 2.

Each channel of the fuel pump driver has its own power supply line.

3 Injection

The fuel system process provides fuel at correct pressure into the injectors rails. The injection process injects appropriate amount of fuel into the air and the mixture is then sucked into the valves. This section describes the injection process. Figure 7 illustrates the main interactions.

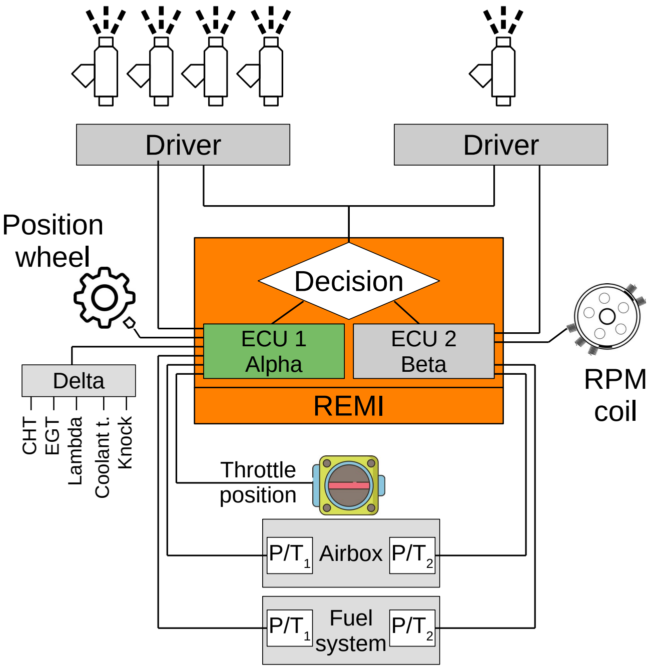

Figure 7: Injection schematics and connections with Remi modules.

Remi system is using two independent (parallel) injections processes. They both do a similar job. The main system is governed by ECU 1 and the backup system by ECU 2. Each of these have different fuel line for maximal redundancy.

3.1 ECU 1

ECU 1 controls the main (primary) set of injectors. These are four injectors that are mounted just before the intake valves. In order to inject correct amount of fuel, the ECU must combine information from different sensors.

`Throttle position` sensors tells the ECU how much power pilots expects from the engine. Here, not only position is important but also how quickly is the position lever moving (when it is moving).

`Airbox pressure and temperature - P/T` come from a combined sensor. The pressure in the airbox tells how much oxygen is available at the certain moment. Higher the pressure, higher is the air density. In similar way lower temperature means higher density. Put into another words, these two tells how much oxygen is available for the fuel oxidation.

`Fuel pressure and temperature - P/T` come from a combined sensor and they are used to check for the pressure correctness and also to adjust the injector timings according to fuel-pressure variations.

`Position wheel` is used to calculate the engine speed (RPM). It tells how quickly is engine turning in the moment.

In addition to the essential sensors above, there are feedback sensors, which are used to inform or fine tune the injection process. These sensors are connected to the Remi Delta module. The module performs AD signal convertion and transmits the sensor values on the internal CAN bus, where all other modules can take advantage of this information.

`EGT` Temperature difference between EGTs is observed. Ideally the difference shall be zero. Small difference is tolerated and large difference tells that cylinders are not working on the same regime.

`Lambda` is used as a feedback for the AFR value. This value can be compared with the target value for given regime.

`Coolant temperature` is used for engine health monitoring and also for the cold start.

`CHT` are used for engine health/condition monitoring.

The information form these sensors is used to calculate the amount of fuel to be injected into the engine. This value is then used to calculate how long the injectors will be open.

The injector timing signals pass directly to the injector driver. The driver then checks which ECU is in operation and either passes signals to injectors or ignores the signals.

3.2 ECU 2

ECU 2 runs in parallel to the ECU 1. It is completely independent. It gets fuel on its own rail. The principles are similar, but there are also some subtle differences. ECU 2 is tuned to be less complex and more robust. ECU usually commands only one central injector (it is capable of commanding two injectors if this is appropriate).

`RPM coil` is an independent signal source for the engine speed. It is not related to the position wheel. The speed from the coil is not very responsive and provides only average speed.

`Airbox pressure and temperature - P/T` is used in the same way as in ECU 1, but here the information comes from different sensor.

`Fuel pressure and temperature - P/T` is used in the same way as in ECU 1, but here the information comes from different sensor.

Non-essential information like EGT and CHT temperatures are mostly ignored. Coolant temperature is one exception and is used for the cold start adjustments in the cases, where a cold start is performed on ECU 2.

The injector timing signals pass directly to the injector driver. The driver then checks which ECU is in operation and either passes signals to injectors or ignores the signals.

3.3 Decision

The decision module decides which injection driver is active at the moment. The decision reasoning is pretty complex and it is covered in a separate section. See section 5 on page 21.

4 Ignition

The ignition system ignites the compressed fuel-air mixture in pistons with the help of spark plugs. The Remi's main role here is to calculate the optimal time for the ignition start. Figure 8 illustrates the main components involved in the ignition process.

Again, two independent processes are running in parallel. The first process is controlled by ECU 1 and the second by ECU 2.

Eight spark plugs are used in two ignition lanes named as A and B. This means that each cylinder has two spark plugs. One is from lane A and the other from lane B. These two lanes have independent ignition coils (two plugs per coil). This system gives some redundancy even without Remi. If one lane fails, the other is still operating.

The A and B lanes are controlled via ignition module. Only one ECU at time controls the ignition module, which in turn controls both ignition lanes. This is slight deviation from the principle that was used so far. One may expect that ECU 1 would control lane A and ECU 2 would control lane B. This is possible of course, but in this case, ECU 1 and ECU 2 has to run the same software and they both have to start ignition in the very same moment. ECU 2 is designed to be more robust and has a bit conservative ignition timings and for this reason only only one ECU controls the ignition at given time. The decision circuit decides, which ECU is in command.

ECU 1 takes all advantage of the sensor information and dynamically changes ignition timings accordingly to the engine speed and airbox pressure. This allows optimization for maximal power and also maximal efficiency (not at the same time, of course).

ECU 2 is more conservative. It focus on robustness. It does not vary engine timings and simply uses default ignition coil signals. On the downside, this does not allow optimizations, but on the upside it allows robust ignition implementation.

4.1 ECU 1

ECU 1 is tuned for maximal power at maximal engine speed and maximal economy at cruise RPMs (below 75% of maximal engine speed). In order to achieve this, ignitions times must be adapted according to given engine operating regime. This is only possible when very precise crankshaft position is known at any time. This information is obtained from the position wheel sensor. Ignition timing depends on the airbox pressure and engine speed.

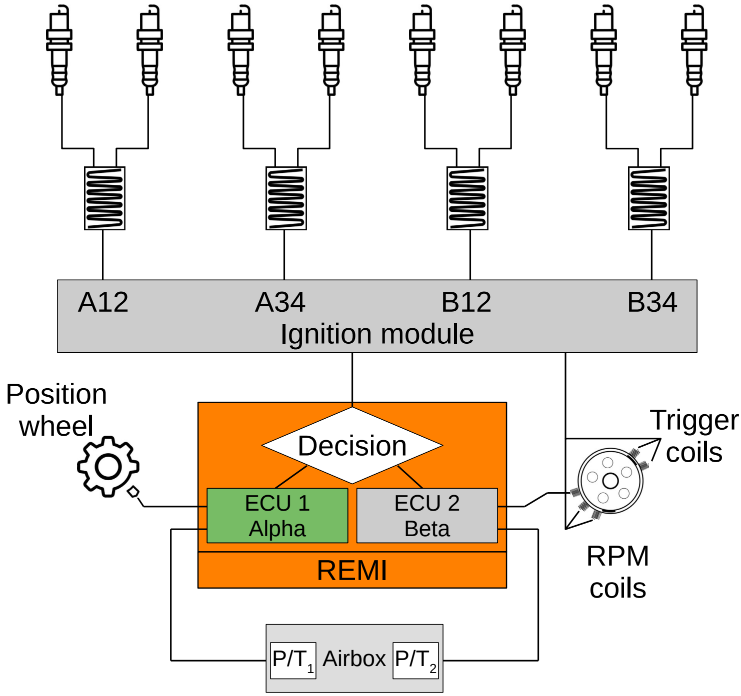

Figure 8: Ignition schematics and connections with Remi.

Ignition timing is usually expressed in angle before the top dead center of piston is reached. This information is calculated from the engine speed and airbox pressure and engine speed. ECU then converts the resulting angle into the time point, when ignition has to happen. Exact position is essential here.

4.2 ECU 2

ECU 2 works on robustness principle. ECU 2 does not have reliable information of the crankshaft position and this it can't take advantage of variable ignition timings. Instead, default solution with the ignition coil positions is used. This allows two different timings. One for engine start and the other for normal engine run.

ECU 2 does not interfere with these timings at all. The timing signals from four ignition coils are passed directly to ignition module. ECU 2 only participates in health status calculation and feeds this information into the decision block logic.

4.3 Decision

The decision module decides which ECU drives the ignition module. The decision reasoning is pretty complex and it is covered in a separate section. See section 5 on page 21 for more details.

5 Decision

Remi consists of two separate and parallel engine control units ECU 1 and ECU 2. They are operating in parallel. In the case of the critical failure of the main control unit (ECU 1), the system must be able to switch to the backup control unit (ECU 2). Additionally, the system must also take into account pilot selection. This decision is made by the *Decision module*, which is described in this section.

The decision module continously receives ECU 1 health pulse. At the same time it also receives the state of the ECU selector switch, which is operated by the pilot. Based on this information it decides which signal will propagate to the injection and/or ignition output driver. The decision logic inside Remi allows only one output module to be active at the time.

Figure 9 illustrates the situation.

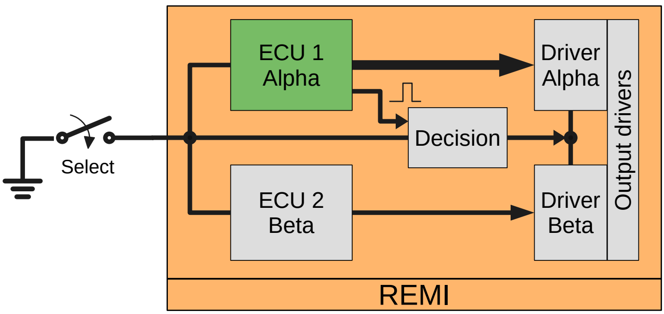

Figure 9: Decision block diagram within Remi.

This gives three different situations:

`Normal situation` is when both ECUs are running in parallel. They both prepare and generete signals for their injectors and ignition even though only one is de facto activated. Depending on the health signal from the ECU 1, the decision module activates output driver alpha or driver beta. Driver alpha propagates signals from ECU 1 and output driver beta propagates signals from ECU 2.

`Pilot override` depends on the position of the selector switch. This is done by the pilot and overrides the automatic logic described in the previous item. It is worth to mention that ECU 1 and ECU 2 are able to detect the selection switch failure.

`Decision module failure` was also considered. The hardware logic of the output drivers is such that one of the drivers is always active regardles of the status of decision module. So, if ECUs are running properly, the engine will continue to run.

6 Power

The Remi system needs electrical power to function properly. This section describes the power management in the Remi system.

Electric power is a critical component in the injection system because without electric power engine will stop immediately. Therefore the *Remi power system* is designed as triple redundant system with optional backup battery as fourth power source. All sources are capable of supplying the internal Remi power bus.

Figure 10 illustrates the four sources:

- Remi DC/DC source from the generator.
- System DC/DC source from the generator.
- Main battery source from the system battery.
- Optional backup battery just for the Remi system.

6.1 Power Sources

The main power source is integrated Rotax generator mounted on the engine crankshaft. The output of the generator is AC with output voltage 10-40V.

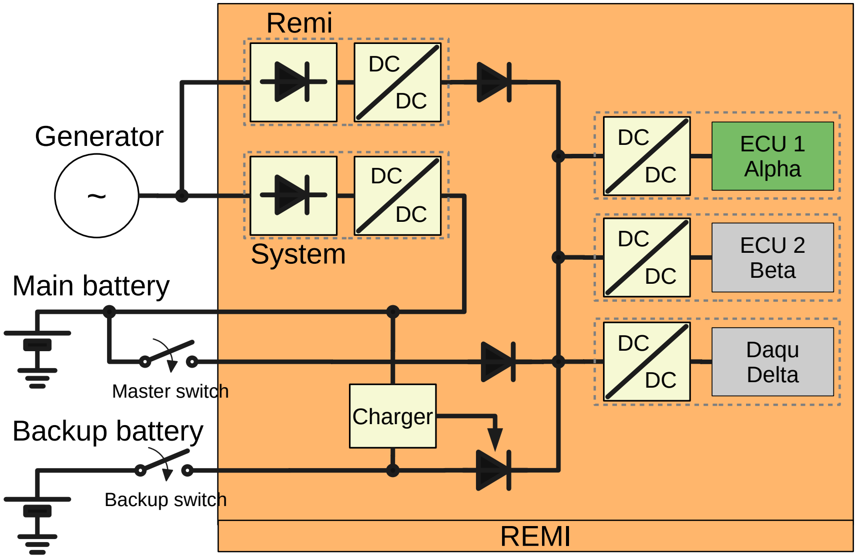

Figure 10: Power schematics and connections with Remi modules.

Generator provides power source for two parallel voltage regulators - *Remi* and *System*. The *Remi* voltage regulator is the main regulator for Remi system and the system power regulator is dedicated for all other electronics (including Remi).

6.1.1 Remi DC/DC Source

The AC power from generator is rectified and then regulated by a DC/DC regulator. This regulator is the primary power source dedicated solely to Remi. It provides slightly higher output voltage than the system regulator.

6.1.2 System DC/DC Source

The system DC/DC regulator runs in a parallel to the Remi DC/DC regulator. It provides power for all electrical consumers in the aircraft. If the Remi DC/DC regulator fails, it provides power for Remi as well. The system power regulator is supplying power to the aircraft system only when the Remi DC/DC power regulator has enough power to supply the Remi. If this is not the case, the system and avionics are shut off and all power is transferred to Remi.

6.1.3 Main Battery Source

The main battery source is used to power the system until the engine is started. After this it sits in the stand-by for potential failure of both DC/DC regulators or in the case of generator failure.

When the *Master* power switch is switched ON the Remi system is able to get electric power through System power regulator even if there is no battery connected.

6.1.4 Backup Battery Source

This is the optional, fourth source of electrical power. It is designed to provide power for the Remi only. It can be used to provide emergency power for the unlikely case of generator failure and for the main battery failure.

6.2 Remi Modules' Internal Regulators

Each of the Remi modules has also an internal DC/DC regulator which provides correct voltage for micro-controller and other circuit logic.

The input voltage on these regulators is between 12 and 14V depending on the state of the power sources, but it can also be as low as 3V under cranking condition. Each module then converts this input voltage to one or several other stabilized voltages as required by electronics.

This enables Remi to be start engine under ECU 1 and ECU 2 control and it also makes the system more robust.