DCC for Large Modular Layouts

By Reinhard Müller

1 Introduction

Before starting with the technical stuff some words how FREMO came to DCC. While within FREMO there are multiple groups modelling in different scales and different prototypes, the H0 scale European prototype standard gauge group is the largest and the first to move to DCC. Therefore the following concentrates on this part of the FREMO, which represents about half of the members.

1.1 First Try

The first try with a digital command control system was in 1991 using the Selectrix system. This system had been developed and was exclusively sold by Trix. This try failed miserably. At that time I didn't know about FREMO and have therefore no first hand experience, what went wrong. But the approach used was calling for failure.

For analogue operation we had a main bus carrying AC power, a clock signal and five wire pairs for five cabs. Five colours were associated with these five cabs. This allowed for five train crews plus local cabs to be used in a single station only.

When trying to run digital a single "colour" was driven by a single booster. Due to all the interconnections and the thin wiring and switches in the stations the signal became distorted enough that at a certain distance control was lost. After this failure digital control was off the agenda for several years.

1.2 Another Try

The group modelling US prototype had a try with the Lenz system. As they didn't want to produce a failure like the try with the Selectrix system, they did this just within their group without others knowing. They had a good set-up with sufficient boosters and it all worked. But they were annoyed that the whole layout shut down, when there was any short on the layout. They simply missed the point to disconnect the "E" terminal of the boosters to prevent this. But the time to go digital had come.

1.3 NMRA DCC

In 1996 a member came back from the NMRA national convention in Long Beach, talking about a standard for digital command control. And that this standard was accepted by the manufacturers. Not like many of the so called "paper tigers" within the European standards. This was the chance to decide for a system not restricting us to the products of a single company, which may go down or decide to discontinue the system. But the failure and problem reported above show that some preparation is needed, before we try to run a modular layout with a digital command control system.

2 What's special

The major question is about the differences of modular layouts compared to stationary ones. The following points address free form modular layouts as set-up by FREMO or Free-Mo.

a) The layout is not permanent: All cables have to be pulled along the layout for each meeting. Therefore we don't want to pull any more cables than the minimum and no really heavy cables around the layout!

b) Less "compact", same amount of track results in longer cable runs.

c) Each time different. There is no fixed topology.

d) Set-up has to work almost instantly. As the time of a meeting is limited, nobody wants to loose time for operation due to technical problems.

These points will be discussed in detail later, when I explain our solution. But as a summary the system needs to be oversized to a certain degree. Those from the Northeast of the US and Canada may remember what a marginal power supply system can result in. ;-)

3 System selection

3.1 Other than NMRA DCC?

First we took a final look back to the systems not compatible with NMRA DCC.

- Märklin-Motorola: This system is mostly used with 3rd rail "AC" layouts. As Märklin is the largest model train manufacturer in Europe and started their digital system in 1984, there are a lot of users. But it has too limited features: 80 addresses (256 with some second source), 4 functions, 14 speed steps (28 with some second source) and no throttle bus. No chance for that system.
- Selectrix offered 112 addresses, 31 speed steps with a fixed internal speed curve allowing smooth switching, all decoders with BEMF. For more than two functions a second address would be needed. The system didn't look bad but had some drawbacks. The TTL level throttle bus is not really suited for large bus length exceeding several 100 foot. There is still only one decoder manufacturer. It was exclusively sold by Trix with Trix being just taken over by Märklin, resulting in an unknown future. This is an example of the problem, when you are dependent on a single manufacturer.
- The other systems like Fleischmanns FMZ and Zimos proprietary protocol had no real future and were therefore not considered. Both companies are now selling DCC while supporting their old systems.

So we decided to go for NMRA-DCC with multiple manufacturers supporting that protocol, which also gives us choices between different decoders and the competition results in lower prices. But before we could start to design our system in detail, we needed to know the throttle bus, as this is system dependent. So we had to select a manufacturer to start with. Most of the selection process was done in the first half of 1997. So the system comparison reflects that state. However I will note where things have changed.

3.2 Our needs

Whenever you start to select a system you must list your needs.

- Support of short and long addresses at the same time to allow the members to use <u>any</u> DCC decoder.
- Support of 14, 28 and 128 speed steps at the same time for the same reason.
- Cab bus length minimum 1000 feet. (350 feet already reached with analogue operation, some growth expected, 1500 feet reached with DCC)
- No throttle IDs (nice to have).
- Dumb throttles for train crews.

The dumb throttles should not allow to select an address on its own, to prevent less experienced members to select a wrong address and produce a crash far away. Also it should be fully operational with either the right or left hand and be as slim as possible. During the selection process we discovered that we didn't like any of the throttles for train operation. We obviously had too fixed ideas about this throttle. So we had to build it ourselves and the list had to be changed. Instead of the throttle requirement we needed:

- The protocol of the throttle bus must be available
- The throttle bus must be easy to interface to.

3.3 DCC Manufacturers

We looked at the major manufactures Lenz, Zimo, SystemOne (NCE was just starting their own system) and Digitrax.

As you would expect from a club mainly located in Germany, we first looked at **Lenz**. But at that time the Lenz system offered only short addresses and 28 speed steps. The throttle bus was limited to about 330 foot. As the decoders already supported long addresses (but not published in Germany!) and as the used RS485 bus does allow for larger distances, we asked whether there would be a change to be expected. But the answer "Who needs that?" disappointed and we dropped Lenz. Now Lenz does support long addresses and 128 speed steps and has largely increased the specification for their bus. But there is still a limit of 30 throttles using IDs.

Next stop was **Zimo**. That system is quite expensive, while clearly worth it. It offers features still not found in most systems. This includes feedback like the Digitrax Transponding, but the Zimo system was already available in 1996. There are stop and restricted speed sections available for automatic train control. These sections are designed in way, which can easy cope with locos bridging the gaps. But all those special features are not needed within FREMO, making the system too expensive. And we wanted a system, where also entry level systems were available. A final drawback was the CAN-Bus used. It needs special devices to interface it, making DIY throttles more expensive.

This made us look across the Atlantic with **SystemOne** / **NCE** and **Digitrax** offering what we needed. So the decision was based on the throttle bus. SystemOne and NCE use a polled RS485 bus like Lenz, but at a lower data rate. The LocoNet from Digitrax uses about the same data rate, but with an event controlled protocol. The computer science people in our club liked the LocoNet, as it also allows transmitting information not addressed to the command station. Furthermore we like to have both the cab bus and the booster control bus in a single cable. Another point was the lack of any distributor for SystemOne or NCE in Europe. Today there is just one dealer in Norway importing NCE.

So we decided to use the LocoNet, after re-insuring that the protocol for the LocoNet would be available. The first command station, a Digitrax DCS 100, was bought on the 1997 NMRA-Convention in Madison.

4 Implementation

One of the special things about FREMO is that nearly nothing belongs to the club. All is owned privately. Therefore we, the DCC promoting "Digitalos", had to set-up the system in a way that it could be added easily to the existing modules. Having nothing of the DCC system integrated into the modules also helps to debug the system. All components can be easily swapped in case of a failure. When the layout is up we want to operate and don't want to waste time searching for bugs.

4.1 Boosters and Grounding

As noted above we try to minimise the wiring both in number and size. As we have to be able to connect throttles at any place, the thin LocoNet-cable, carrying both the cab bus and the booster control signal, is the minimum. This results in the use of distributed boosters. For sure there is also a cable parallel to the track to avoid a too high resistance. That is the cable already used in the analogue times.

The boosters are always located near the centre of the district they supply. This not only saves the number of quite solid cables to be pulled around the layout, it also prevents the problems of very long cable runs. With "smaller" layouts all boosters at a single place may work, but with more than 100 to 200 foot between booster and track the digital signal will be easily distorted and you loose control. Garden railroads prevent this with boosters controlling the slopes and thick wiring without too many interconnections. With our concept we allow for "not up to standard" wiring in stations from the analogue era.

As a modular layout is thin and long, resulting in each district having only few neighbours, we also don't use power managers. They would also spoil the idea of the booster to be close to the supplied section. Instead many low current (2.5 to 3 Amps) boosters are used. All shorts are handled locally. There is no need to bother the whole layout with a single short e.g. due to running a switch set against the train.

With that approach we need to take a close look at the grounding. For sure we use what is called direct home, with both rails gapped between booster districts and paired cables. But if just one of the two gaps is bridged we get a current loop from one booster over the track, the bridged gap, the other track to the next booster and back via the common ground between the boosters. Typically Digitrax boosters have the LocoNet ground connected to the internal booster ground. Letting the current, driven from the always present small difference in voltage level and timing between boosters, running along e.g. 30 foot of the thin LocoNet wires would result in significant voltage drops and result in damage to the ground referenced cab bus signal.

Therefore the grounds of the boosters need to be connected via a solid wire, preventing the voltage drop along the LocoNet cable. Or we could use separate LocoNet-cables to connect just the boosters. Both would require another cable to be pulled around the layout. Therefore we choose a different solution:

Opto-insulation. By this the connection between the LocoNet and the booster is cut. There is no path back in the above noted current loop. There is no current flowing from one booster to another, except both gaps bridged. It is always a good approach to keep power and control separate where possible. Any problems on the power i.e. track side will not result in a problem at the LocoNet. All problems will stay local!

But as all solutions this has some implications. First locomotives with offset pick-ups, e.g. brass steam with right pick-ups at the engine and left pick-ups at the tender, may stall on the gap. But we anyhow consider offset pick-ups as a bug, which needs to be fixed.

The second is more severe, as any connection between track and LocoNet needs to be avoided. Therefore the track connections of the UP3 and UP5 modules may not be used. The throttles may not be powered from the track signal! And having a wall-wart at each UP3 or an extra connection between the UP3s are also not practical. Therefore the throttles are only powered by the RailSync – the booster control signal.

4.2 RailSync Boosters

Powering all throttles from the RailSync signal will work at a small layout without problems. The RailSync output of a DCS100 has 27 Ohms resistors in series to limit the current. With this it can supply about 125mA between RailSync lines or about 250mA between RailSync and ground before the voltage drops below 7 Volts -- the minimum for reliable operation. With each throttle drawing about 12 mA and each booster also needing about 10 mA for the LED of the opto-coupler, about 4 boosters and 14 throttles are the maximum. Actually it is a bit lower due to voltage loss along the thin cables.

The simple solution would be to increase the power driving the RailSync signal. But the thin cables should not be loaded with more than the 250 mA. So we are dividing the net into subnets, each with a separately powered RailSync. To power the RailSync any booster with additional resistors in series may be used. If it is a booster with an opto-coupler at the input, we need to get a ground reference again. This can be done easily by adding two diodes.

Initially we had each time a booster with its pair of resistors and diodes. But actually several sets of resistors may be powered by a single booster. And as we want to keep the track and the control separate, there is already an unused booster in the DCS100 command station. And as this booster is already connected with its ground to the LocoNet ground no diodes are needed. So simply a field of resistors is added to the DCS100 output and connected to several RJ12 sockets.

4.3 Wiring

As a result of the above we come to a star type topology. From the central RailSync booster several branches go into the layout. As the layout is most often not exactly this topology, there are some branches with up to 100 foot of wire before the first throttle socket. But this has shown to be better then a more linear topology. The large set-up at Kassel was quite linear and we had some extra RailSync boosters along the line. But the voltage drop on the ground line added up. It could be easily seen by the logic low level shifted up by up to two volts for the most remote throttles. This is still within the limits of the LocoNet, but shows clearly that we were going towards its limits.

As we normally don't use UP3 or UP5 due to their price and as we can't use their special features, we created plug-in boxes, which can easily be attached to the modules. It has four sockets, two for the main LocoNet bus and two for throttles. The LocoNet is routed from box to box with some diversions to connect to the boosters. Depending where the train crews are walking, sometimes boxes on both sides of a module are needed. Therefore the total length of the LocoNet bus is longer than the length of the modules. Together with the extra runs to the RailSync booster described above we estimate this overhead by 20 to 30%.

Though the DCC components may be added to any modules, the owners of large stations have included a fixed LocoNet into their modules. This speeds-up set-up time and the cables are cut to optimum length. As large stations dominate their vicinity, the sockets for the throttles will be placed always the same way anyhow. Also the wiring can be optimised for minimum resistance through the station by implementing a star configuration. But still it must be possible to disconnect branches within the station for easy cut-off of areas causing trouble. In this case the normal boxes are the back-up solution.

For simple track modules this doesn't make sense, as sockets will be needed each time at different places and there will be no plug in box at each module. Fixed LocoNet within simple track modules will increase the number of interconnections with their associated resistance. Also overall cable length would be increased.

Many stations have included boosters into their station. If also the LocoNet is included, it will be directly connected. But the LocoNet cable connection to the booster will be done by the normal RJ12 plugs to allow disconnecting them from the LocoNet. The power outputs should have the standard 4mm sockets as used to connect modules. This allows easy replacement of a failed booster and also allows easy polarity change.

4.4 Polarity

With modular layouts there is almost no chance to insure the polarity – or better phase – of the boosters to be correct in the first place. A station turned by 180° within the layout will result in a booster district out of phase. Therefore we take another approach: Once the modules, LocoNet and boosters are set-up on a branch, we check the phase either with a small tester or just by going along the track with a loco, watching the short indicators of the boosters. Going along with a loco has the advantage to find other track wiring errors as well. Whenever there is a short at a booster district boundary, the phase of the "new" booster is adjusted by simply swapping the two 4mm plugs at the booster output. But which is the "new" booster? We simply define one central booster district as correct phase. Then we go along the track from this central point into the branches. So "new" defines the booster further away from the starting point. This definition works, as our layouts never loop back or form a circle.

Within larger stations there are multiple boosters. These may be kept in phase by connecting them with their own LocoNet and a single RailSync polarity switch changing the polarity of all boosters within the station. But this switch must not change the polarity of the RailSync of the main LocoNet line.

4.5 Throttles

As described above we were not satisfied with any of the commercially available throttles. We wanted the following key features:

1. A pod for speed control with a direction switch.
2. Single hand operation with either hand.
3. As slim as possible.
4. No address selection on its own.
5. No battery, requiring a low current design.

The first is just a choice of taste, based on the analogue throttles we were used to. The pod allows feeling the stops at zero and full throttle, so you can operate them blind. The second is really needed to have one hand free for an uncoupling tool while switching. The third option allows to "parking" some other things like car cards temporarily in the same hand as the throttle, while being still able to operate the throttle.

The fourth point actually kicked out most available throttles. But with many inexperienced users, operating the system only a few times in a year, we wanted to avoid the selection of a wrong locomotive. Imagine someone selecting the wrong address by accident. The loco he wanted to select will not run. He will put up the throttle, give the loco a push, try different things, while the actually selected loco, which may be anywhere on the layout, will perform unintended movements, possibly resulting in severe damage.

The last point was clear from start, as the throttles will be needed continuously for many hours during a meeting, but will be idle for several months between meetings. That would require some special handling of batteries, we wanted to avoid.

I must admit, that we would have dropped almost any feature for wireless operation. But this is not an option so far. The infra red systems will not be able to cover our layout sizes, even with multiple receivers. To keep line of sight contact within crowded places is nearly impossible. Walls and ceilings are too far away and of too different kinds to help the reception of the signal. The radio systems available in the USA are not allowed in Europe due to different frequencies used.

The first name of our throttle was SLNTHR for Simple LocoNet THRottle, which was difficult to pronounce. A better Name was found: FRED (FRemos Einfacher Drehregler = FREMOs easy throttle). Our throttle had to be developed in time for the first meeting fully run with DCC. This was putting some pressure on the designers.

Image

Caption: The FRED throttle

The effort developing a throttle was worth while, as the very easy to operate throttle showed our members, how easy operation of a digital system can be. Nobody had any trouble to operate it. All were pleased that they could unplug the throttle to move to the next socket while the train was moving. This avoided frustration due to the lack of wireless operation.

During the first meeting we had several technical problems. One was due to poor pods, not strong enough being operated with the thumb or breaking on the first drop to the floor. We replaced it with a better one, which is now the most expensive single part. But it is the main user interface! The second problem was due to the controller going mad during power cycles when the throttles were not plugged in correctly. This resulted in loss of stored data. Either they forgot the number of the loco to control, their identity believing another throttle would control their train or lost calibration data being unable to stop the train. But since we solved that problem by the use of a reset device including "brown out" detection, the throttles work very reliably.

When the throttle was designed we estimated up to 30 throttles to be built to have enough for all meetings. As we keep the throttles assigned to the locos throughout the whole meeting, we need more. But what we did not take into account were the members wanting to have throttles for use at home. Also several have a throttle for each loco they bring to a meeting. Currently more than 2000 PCBs have been produced on request of members. If we would have known that, the design would have been different. At least no calibration needed. On the other hand this shows the popularity of our FRED.

4.6 The use of the long addresses.

One of the requirements of the system selection was the long addresses. While in the US the use is clearly to match the road number this is not possible in Europe. E.g. the locos of the German railways have 6 digit road numbers plus a control digit. But the long addresses allow to give each loco in the club a unique address within its scale. To ease the administration members or small groups get a block of 100 addresses. Within this block it is their responsibility to assign unique addresses. If there are more than 100 locos in that group they will get another block.

So far it looks as this system will work for a very long time. As most members have converted their existing locos to DCC, there is only a little growth expected in the number of addresses needed. Most people realise that they can't operate multiple locos at the same time – consists are rare in Europe.

4.7 Multiple command stations?

One of the primary rules within digital control says that *there can be only one* command station. So what is the point of having multiple command stations on a single layout?

The bandwidth of the DCC packet stream is limited. While there are only a few addresses active, each decoder gets a packet quite often. But with more than about 10 to 15 locos this rate drops below ten per second. (A 128 speed step packet to a long address takes about 9ms.) With 20 to 30 active addresses you start to feel the delay between the throttle change and the reaction of the decoder.

Most DCC systems try to improve this situation by giving changes a higher priority. Those addresses where there is no change in speed get a packet less often to allow changes to be transmitted faster. This works especially good with computer controlled layouts, where most of the trains travel at constant speed most of the time. But when all addresses are manually controlled with an operator permanently changing the throttle setting for smooth acceleration, switching or just gradually slowing down in front of a red signal, this priority scheme is not working. When the engineers start to feel a delay they begin to continuously test the response time to be sure to still have control over their train. This makes the situation actually worse.

The only chance to increase bandwidth is to divide the layout and generate separate DCC packet streams for each part. But how can a train move from one part to the other as the track signal is different and crossing the gap would produce a short? The solution is a section of track, which can be switched between two booster districts connected to the different command stations, and long enough to hold the longest train. When the engineer plugs his throttle into the LocoNet of the new command station, it starts to produce packets for the train address. The track section can be switched while the train is in motion without any change in speed. If the throttle is plugged in later, the decoder will see a DCC signal and continue with the same speed until it gets new information.

The implementation is quite simple: A bi-stable relay and some pushbuttons, attached to the modules. Each of the neighbouring stations may switch the section to its booster before sending a train in that direction. Next to the first LocoNet plug in box of the new system there is a button to switch the section to the new booster district. This system has worked quite well with single track. With double track the train crews would be confused with the buttons for the different tracks. There must be an operator keeping an eye on the correct setting of the relays.

We also discovered a problem of trains returning after only a short time in the other part of the layout. It takes some time for the command station where the train is coming from to detect that the train (and its throttle) has left that part. There is some time-out after the last packet from the throttle to remove that address from the stack of addresses operated. This process is called purging. If the train returns within the purging time either of two things happen. If the throttle is plugged in before switching the section, the command station has a different direction setting for this address; the throttle detects the direction change without speed being at zero and issues an emergency stop. The engineer needs to see the flashing LED, turn the throttle down to zero and back to the old speed to clear the emergency stop condition. If he fails to do so the train will stop when switching the section. If the section is switched before the throttle is plugged in, the train reverts its direction moving towards the old power district.

Both behaviours are not acceptable. Therefore we are working on a solution. This includes a special LocoNet along the switched section. It will be linked to the other LocoNets by a PC. This will detect how the throttle is moved from net to net and initiate purging of addresses leaving a layout part. The switching of the section may be done by occupancy detection around the gaps at the end of the section.

As a summary it is possible to operate multiple command stations, while it takes some care and effort. But with other systems then LocoNet we would have more problems. The address and speed step mode needs to be stored in the throttle to transfer this information to the new command station. With systems requiring unique throttle IDs (like Lenz or NCE), the maximum number of throttles at the layout would not increase. Each throttle ID would need to be unique in all parts as it is not possible to change a throttle ID while controlling a train.

5 What did DCC to our club?

After six years of DCC the major changes due to DCC have settled, but in some areas there is still some movement. The advantages in operations and motor control convinced the members faster then expected by us – the Digitalos. While we expected it to take 3 to 5 years to fully convert to DCC it took less than a year to make DCC the standard within FREMO. When introducing DCC the advantage of modular layouts is the ability to decide for each meeting separately, which control system to use. During the transition time you may have both digital and analogue meetings. We even swapped system during a meeting to present the members a direct comparison. The problem was that all motive power is owned by the single members. So each member had to be convinced to put decoders into those locos he wanted to operate at meetings.

Looking back, the biggest change is possibility to control larger layouts. With the old analogue systems the number of train crews was limited to five. Using two in parallel – each on its own part of the layout – would have allowed 10 train crews. But with DCC more than 20, even more then 30 are no longer a problem. With this a double track mainline becomes feasible. With just 5 train crews there is just not enough traffic to justify two tracks.

We are also able to operate larger stations. Switching the power for each train in our large stations would be a nightmare. With multiple trains and several switching crews active at the same time, as people are getting locos out of the workshops, would be hard to handle. Our two biggest stations actually date back into the pre-DCC era, but they would have required a 10 train crew set-up and all the block switches. Therefore these stations did not appear at any meeting, before DCC was introduced.

But even smaller layouts with the same stations as used in the analogue times are running more reliably. With the old bus system a problem in one station was "exported" into the whole layout. Two blocks set for different cabs and shorted by a loco on the gap resulted in problems far away where the other train crew was active. And more switches result in more chances for failures and operational errors. Each time we tried to go to the limits of the analogue system, people were so frustrated of all the technical problems that it took more than a year till the next try for a larger meeting. Please note that these former large meetings are now more close to the average layout size. Since we operate with DCC the size of the halls available and the time to set-up the layout have become the limiting factors.

The work at the signal tower is getting closer to prototype. There are no block switches needed in the control panels. And the operator can concentrate on the tasks of the prototype. As trains are no longer protected by their electrical blocks, interlocking mechanisms preventing collisions at the prototype become more important.

The success of DCC within the H0 scale European prototype standard gauge group of the FREMO made other groups to try DCC as well. Today most groups are using DCC.

As a summary the operation has improved a lot and is getting closer to prototype. DCC has proven to be a major step forward within the development of FREMO.