*Digi***FM** Optimal

FM processor, stereo coder with RDS, transmitter and receiver · PE1PzN · SDR7020 with AD9363 · manual for version 1.0.1, FPGA 0.29 (22 October 2026)

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> **Only for radio amateurs and radio research, not for commercial use.** The program, the files for the SD card and this manual are given free of charge as they are, without any warranty. Use is at your own risk: PE1PzN is not liable for damage to equipment, interference to others or any other result of its use. You may only transmit within the terms of your own licence and on frequencies where you are allowed to; that is your own responsibility.

1. What is DigiFM-Optimal

DigiFM-Optimal turns an SDR7020 into a complete FM broadcast transmitter. Everything sits in the FPGA of the 7020:

- an **audio processor**, like broadcasters use: AGC, equalizer, multiband compressor, sub bass, HF limiter, limiter and clipper;
- a **stereo coder** with pilot, RDS and a composite clipper;
- an **FM transmitter** with MPX clipper and a steep 200 kHz channel filter;
- an **FM receiver** that plays straight to a DAC board.

Plain stereo audio comes in (left and right). An FM stereo broadcast with RDS goes out. There is no PC in the audio path and there is no delay: what you say goes on air at once.

The program on the PC is the control desk. You set everything with it, you see all meters on it and you measure your own broadcast with it. If you close the program, the transmitter switches off.

The FPGA design it started from is by Willem, PE1PCF: github.com/Willem65/Vivado-Zynq-7020-Chinese-ADALM-Pluto-kloon.

2. What you need

Part	Explanation
SDR7020	Zynq 7020 SDR with AD9363 (a Pluto clone, 70 MHz to 6 GHz). A board with an AD9361 also works.
Micro SD card	With the files of DigiFM-Optimal (FAT32).
I2S ADC board	For the audio into the 7020. Without this board the chain stands still.
I2S DAC board (PCM5102A)	Not needed to transmit. But handy: you hear what the processor does, or the receiver.
Windows PC	With USB or network to the 7020.
Attenuator, maybe a splitter	To measure and align your own transmitter (chapter 14).

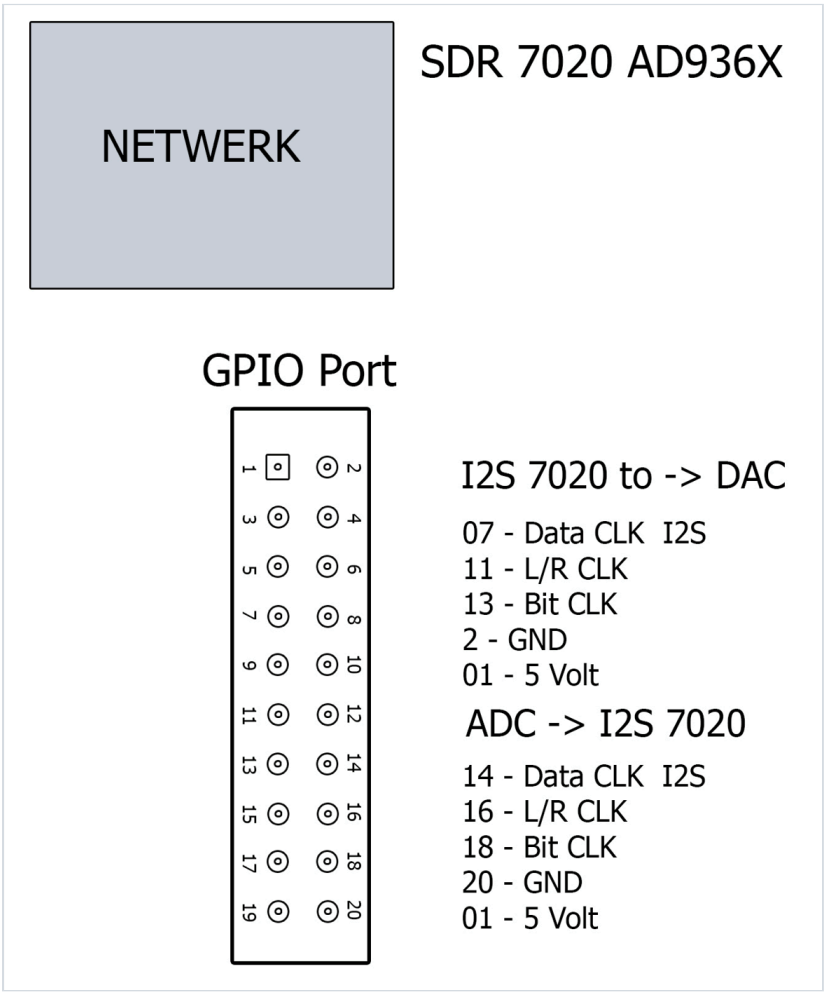
> **Use TX1 and RX2.** The transmitter comes out of **TX1**. You measure and receive on **RX2**. RX1 sits on the board right next to TX1 and picks up the transmitter directly. Then you measure the board and not the signal.

3. Connecting (I2S boards)

The audio comes in **analogue** on a small I2S ADC board close to the 7020. That board turns it into I2S. Analogue up to the board, because I2S cannot handle a long cable.

```
audio L and R  --analogue-->  I2S ADC board  --I2S-->  JP5 of the 7020  -->  FPGA (processor,
stereo coder, transmitter)  -->  TX1
RX2  -->  FPGA (FM receiver)  -->  JP5  --I2S-->  DAC board  -->  loudspeaker
```

The JP5 header of the 7020

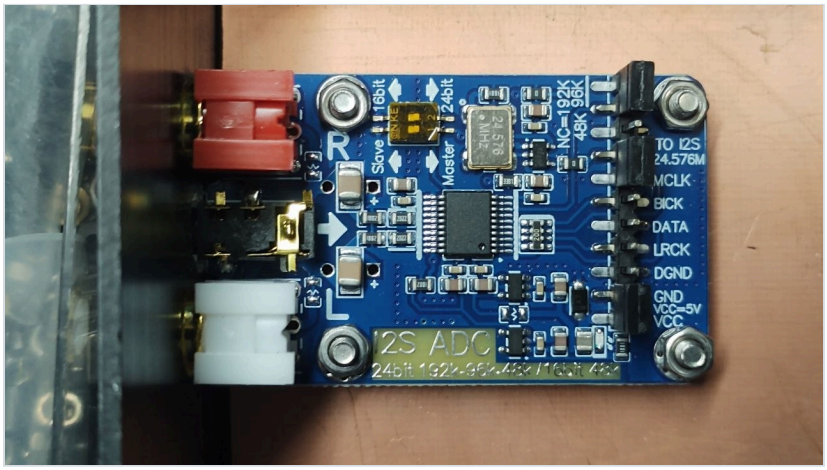


The GPIO port JP5: 2 x 10 pins. The even pins (right column) are on a 1.8 V bank, the odd pins 7 to 13 on 3.3 V.

Pin	What	Pin	What
1	5 V (supply)	2	GND
3	3.3 V (supply)	4	free (1.8 V)
5	1.8 V (supply)	6	free (1.8 V)
7	DAC: DATA (3.3 V)	8	free (1.8 V)
9	DAC: MCLK, not needed (3.3 V)	10	free (1.8 V)
11	DAC: LRCK (3.3 V)	12	free (1.8 V)
13	DAC: BCK (3.3 V)	14	**ADC: DATA** (1.8 V)
15	**do not use** (VCTCXO)	16	**ADC: LRCK** (1.8 V)
17	**do not use** (PTT)	18	**ADC: BCK** (1.8 V)
19	**do not use** (AD9363 SYNC)	20	GND

> Check the supply pins 1, 3 and 5 with a multimeter first, before you connect anything to them. The pinout comes from Willem (PE1PCF), who measured it on the board.

ADC board: the audio into the 7020

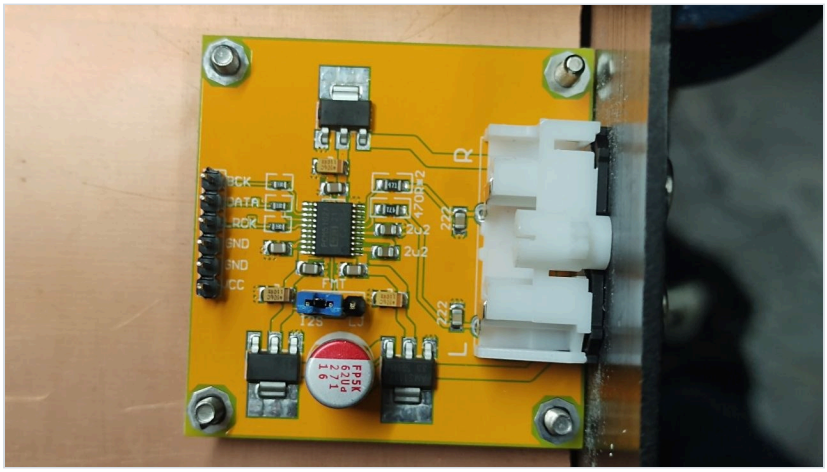


The ADC board: switches on Master and 24 bit; sample rate jumper open (NC) = 192 kHz. Output BICK, DATA, LRCK, DGND; supply VCC 5 V.

ADC board	JP5	Note
DATA (SDOUT)	14	through a divider: 1 kΩ in series, 1.2 kΩ to ground (3.3 V becomes 1.8 V)
LRCK (WS)	16	
BCK	18	
GND	20 (and 2)	

- The board is set to **Master** and **24 bit**. It makes its own clock: 192 kHz.
- The sample rate jumper must be open (NC = 192 kHz). On 96K or 48K it does not work.
- Left goes to the left input, right to the right input. Both channels are used.
- Do not connect MCLK and "TO I2S 24.576M".
- You set the level with the source and with `Ingangsniveau` (input level) in the processor. Watch the Input meter: the `ADC over` lamp must not light up.

DAC board: listening



The DAC board with PCM5102A: input BCK, DATA, LRCK, GND, VCC 5 V; the FMT jumper on I2S.

DAC board (PCM5102A)	JP5	Note
DATA (DIN)	7	3.3 V, direct (no divider)
LRCK	11	
BCK	13	
GND	2 (and 20)	
VCC	1 (5 V)	the board has its own 3.3 V regulators

What the DAC plays, you choose at the top of the Audio processing tab under `DAC` (chapter 8). The FMT jumper of the DAC board is set to I2S. If you only hear crackling, change it over. If the ADC and DAC boards share pin 1 (5 V), split that pin with a Y lead.

4. The first time: SD card, USB and IP address

You need two downloads: the **SD card** (for the 7020) and the **program** (for the PC). They belong together. Always update them together.

Step 1. Making the SD card

1. Take an empty micro SD card, FAT32 formatted. Bigger than 32 GB? Then make a small FAT32 partition in Windows (Disk Management), for example 1 GB.
2. Unzip the SD card zip and put the loose files **straight** on the card, so not in a folder. At the top you then see, among others, `BOOT.bin`, `devicetree.dtb`, `uImage` and `uEnv.txt`.
3. Eject the card properly and put it in the 7020, with the power off.

Step 2. The program on the PC

1. Unzip the program zip to a folder of its own. Python is not needed.
2. Start the program. If Windows shows a blue warning (SmartScreen), choose `Meer informatie` (more info) and `Toch uitvoeren` (run anyway). You only need to do this once.

Step 3. Starting through USB

1. Connect the 7020 to the PC with a USB cable and switch the power on. Wait a good half minute.
2. Press `Zoek` (search) next to the IP address. The program finds the 7020 and fills in the address (through USB usually 192.168.2.1). It does not log in anywhere while doing this.
3. Press `Verbinden` (connect).

USB or network cable?

Through USB the 7020 also becomes a network: a small network between the PC and the 7020. That is handy for the first time, but it is much slower than a network cable. In practice USB reaches about 130 to 200 Mbit/s, and the small processor of the 7020 has to handle all that USB traffic itself. The network port of the 7020 is gigabit. For transmitting, USB is more than enough. But the RF-spectrum and the receiver pull in samples, and then the picture can stutter over USB. So for regular use, use the network cable.

Why is USB slow here? Isn't it USB-C? USB-C only says something about the shape of the plug, not about the speed. Behind that plug the 7020 just has USB 2.0, 480 Mbit/s on paper. But the 7020 does not send the data directly: it acts as a network card, and its small processor has to pack and unpack everything. That is why in practice only 130 to 200 Mbit/s is left. Through the network cable it is different: the network port of the 7020 is 1 gigabit (1000 Mbit/s). That is plenty for everything. Note: your router or switch and the cable must then also be gigabit. With an old 100 Mbit/s switch you only get 100.

Step 4. Through the network cable

1. Plug in the network cable and (re)start the 7020. It gets an address from your router.
2. Press `Zoek` and then `Verbinden`.

Prefer a fixed address? On the USB drive of the 7020, open the file `config.txt` with Notepad. Under `[NETWORK]`, fill in for example `ipaddr_eth = 192.168.0.173` and `netmask_eth = 255.255.255.0`. Save, eject the drive in Windows and restart the 7020.

Is your home network 192.168.2.x (for example with KPN)? Then the SD card solves that by itself.

5. Connecting and starting

The connection details are at the top of the window.

Field	Default	Explanation
IP		Network address of the 7020.
Zoek		Searches for the 7020 through USB and on your network, and fills in the address.
gebruiker (user)	root	Login of the 7020 (as on a normal Pluto).
wachtwoord (password)	analog	
Verbinden		Makes the connection. Then becomes `Verbreken` (disconnect). Verbreken switches the transmitter off.
automatisch (automatic)	off	Ticked: connect straight away at start-up.

After connecting, the program sets everything on the 7020: the processor, the stereo coder, RDS, the frequency, the clippers and the alignment for this frequency. The test tone always goes off.

- Only one copy of the program can run at a time.
- The transmit power is remembered per frequency: what you set with POWER is there again next time. Retuning within 5 MHz keeps the same power. Another band, or a frequency where you have never set anything, starts safely at −10 dB.
- All settings are saved automatically in a file in the program folder.

6. The rack

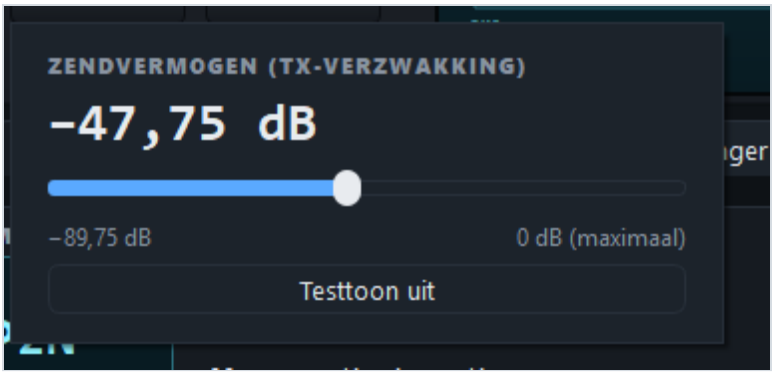


The rack: lamps, buttons, display with the MPX meter, and the TRANSMITTER switch.

The same colour rule applies everywhere: **green** = OK or on air, **yellow** = off air, **red** = something is wrong.

Lamp or line	Meaning
VERBONDEN (connected)	Connection with the 7020.
ON AIR	The transmitter is on.
MPX	There is modulation coming out.
STEREO	The pilot (19 kHz) is present.
7020 SDR	The 7020 answers.
CLIP	The MPX clipper is on. The number is how many dB it takes off the highest peak.
ALARM	Red when there is a problem. The reason is shown below it, for example *zwaai 75,5 kHz (boven 75)* (deviation 75.5 kHz, above 75).
temperaturen (temperatures)	FPGA and AD9363: green below 70 °C, yellow up to 80 °C, red above that.
MPX-vermogen (MPX power)	The average MPX power in dBr, always on screen (chapter 10).

Button	What it does
FREQ	Type in the transmit frequency in MHz (70 to 6000).
PRESET	Preset frequencies.
POWER	Transmit power from −89.75 dB to 0 dB, and the test tone on or off. Use −4 dB as the highest setting.
SETUP	Goes to the Afregelen tab.
DISP	Switches the display: SPECTRUM, METER or STATUS.
▲ ▼	Frequency one step up or down. Right mouse button: choose the step size.
TRANSMITTER	Transmitter on (I) or off (O).



The POWER window: transmit power and test tone.

You can also tune with the mouse wheel: put the mouse on a digit of the frequency and turn. Only that digit changes.

> Avoid frequencies that are an exact multiple of 40 MHz, such as 1280.000 MHz. There the PLL of the AD9363 makes a small wobble. A few MHz away is fine.

7. The audio chain in short

The audio goes through the 7020 in this order. Each step has its own task.

```
Input -> AGC -> Stereo -> EQ -> Multiband compressor -> Sub -> HF limiter -> Final limiter ->
Clipper -> 15 kHz -> Output
  -> Stereo coder (pre-emphasis, composite clipper, pilot, RDS) -> MPX clipper -> channel filter
200 kHz -> FM transmitter
```

Step	Task in one sentence
Input	Set the level right.
AGC	Slowly even out soft and loud tracks. With 3-band also the lows and the highs.
Stereo	Make the stereo image wider.
EQ	Colour the sound, with 7 bands.
Multiband compressor	Make the sound dense and even, per frequency band.
Sub	Add extra deep bass, with its own limiter.
HF limiter	Tame the S sounds and hi-hats, so it does not start to sizzle.
Final limiter	Catch the peaks, without delay.
Clipper	Clip off the last peaks. It is fixed at −6 dB: the output can never get louder.
15 kHz	Remove everything above 15 kHz, so the pilot stays clean.
Output	The level to the stereo coder.

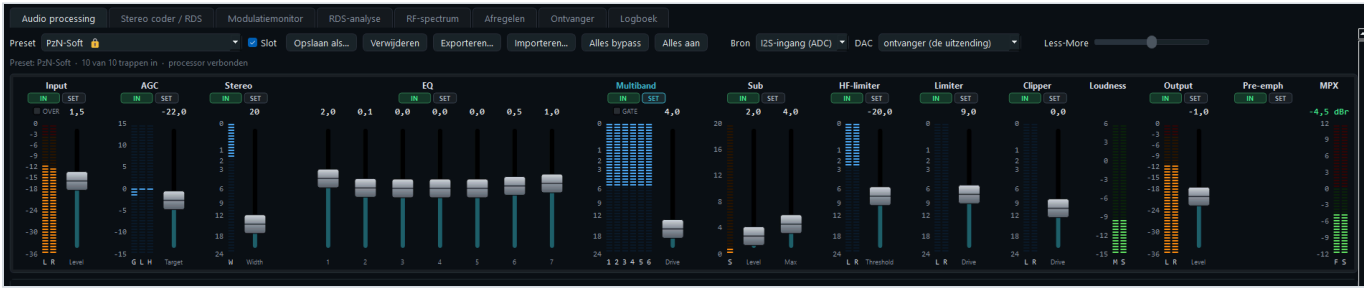
> There is **no delay** in the processor. There is no look-ahead and no buffer. You hear yourself back without delay, even on a radio in the same room.

8. Audio processing tab: the meter bridge

The top line

Item	Explanation
Preset	Choose a preset. See chapter 16.
Slot (lock)	Locks the chosen preset: it cannot be overwritten or deleted.
Opslaan als… (save as…)	Save the current settings under a name.
Verwijderen (delete)	Throw away the chosen preset (not possible when it is locked).
Exporteren… / Importeren… (export… / import…)	Write presets to a file or load them from a file.
Alles bypass (bypass all)	All stages off: the audio goes through unprocessed.
Alles aan (all on)	All stages on again.
Bron (source)	`I2S-ingang (ADC)` (I2S input) or `testtoon` (test tone).
DAC	What the DAC board plays: `rechtstreeks (bewerkt geluid)` (direct, processed audio), `testtoon (vast)` (fixed test tone), `stil` (silent) or `ontvanger (de uitzending)` (receiver, the broadcast). With the receiver you hear what really goes on air.

The meter bridge



The meter bridge: per step the meters, an IN/BYPASS button and the most important slider.

The meter bridge shows the whole chain from left to right. For each step you see:

- the **title**: click it, and all controls of that step appear below;
- an `IN` or `BYPASS` button: switch the step on or skip it;
- the **meters**;
- the most important **slider**. Double-click a slider: back to the default value.

Group	Meters	Slider	What you see
Input	L R	Level	Level at the input in dBFS. Lamp `ADC over`: the ADC board is driven too hard.
AGC	G L H	Target	G = how much the AGC turns up or down. L and H = the correction of the 3-band AGC on the lows and the highs.
Stereo	W	Width	The stereo widening.
EQ		1 to 7	The gain of the 7 bands.
Multiband	1 to 6	Drive	Reduction per band in dB. Lamp `Comp gate`: silence, the compressor holds its setting.
Sub	S	Level, Max	How many dB of deep bass the sub adds (0 to 20 dB).
HF-limiter	L R	Threshold	How many dB the highs go down.
Limiter	L R	Drive	Reduction of the final limiter.
Clipper	L R	Drive	How much is clipped.
Loudness	M S		The loudness in LUFS: M = short (momentary), S = over a few seconds (short-term).
Output	L R	Level	Level to the stereo coder.
MPX	F S		The MPX power in dBr: F = over 1 second (fast), S = over 60 seconds (slow). The number is shown above it.

A blue meter is **reduction**: the further it goes, the harder that step works. An orange meter is **level**. A green meter is **loudness** or **MPX power**.

9. The stages one by one

Below the meter bridge you find all controls of the chosen step, with a short explanation at the top. At the top right are `Standaardwaarden` (defaults: all controls of this step back) and `IN` / `BYPASS`. Grey controls do not work yet; they say "komt later" (coming later).

Input

Control	Range	Default	Explanation
Ingangsniveau	−12 to +12 dB	0 dB	The level of the source. Music should sit on the Input meter at about −20 dBFS on average, with peaks up to a few dB below 0.

> **Advice.** Set your source right first, then the rest. An input that is too soft makes the AGC and the compressor lift a lot, and then the noise comes up too.

AGC (slow level control)

The AGC slowly brings soft and loud tracks to the same level, before the compressor does anything with them. Left and right are controlled together, so the stereo image does not shift.

Control	Range	Default	Explanation
Doelniveau (gemiddeld) (target level, average)	−30 to −10 dBFS	−20	The AGC controls to this level.
Omhoog (up)	0.5 to 10 dB/s	2	How fast it lifts a soft track.
Omlaag (down)	1 to 30 dB/s	7	How fast it turns a loud track back.
Gate-drempel (gate threshold)	−60 to −20 dBFS	−45	Below this it is silence. Then the AGC does not turn up, so the noise does not come up.
Sprong (jump)	3 to 20 dB	8.9	If the audio comes this far above the target, it goes down fast.
Max. ophalen (max. lift)	0 to 25 dB	15	The most it turns up.
Max. terugregelen (max. reduction)	0 to 25 dB	15	The most it turns down.

3-band AGC and the Leer (learn) button

Music sounds different from track to track. One track has a lot of bass, another is sharp. Per track, the 3-band AGC slowly pulls the **lows** (below 200 Hz) and the **highs** (above 2.5 kHz) towards a fixed ratio with the mids. That way your transmitter sounds the same on every track.

Control	Range	Default	Explanation
3-band: max. correctie (max. correction)	0 to 12 dB	0 = off	The most it corrects the lows or highs. 3 to 6 dB is a good start.
3-band: snelheid (speed)	0.2 to 10 dB/s	1	How fast it corrects. Slow is more natural.
3-band: doel laag t.o.v. midden (target low vs. mid)	−20 to +20 dB	0	The wanted ratio low/mid.
3-band: doel hoog t.o.v. midden (target high vs. mid)	−20 to +20 dB	0	The wanted ratio high/mid.

Leer. Play a track that sounds exactly right and press `Leer`. The processor listens for 30 seconds and then sets the two targets itself. After that it pulls every other track in that direction.

On the meter bridge, L and H show how much it is correcting the lows and the highs right now.

Stereo

Control	Range	Default	Explanation
Verbreding (widening)	0 to 100 %	0	Makes the difference between left and right bigger. 0 % = as it comes in, 100 % = twice as wide. Mono stays mono.

> Wider stereo costs deviation. The difference signal (L−R) takes up room in the MPX. If you want maximum loudness, keep the widening modest (15 to 30 %).

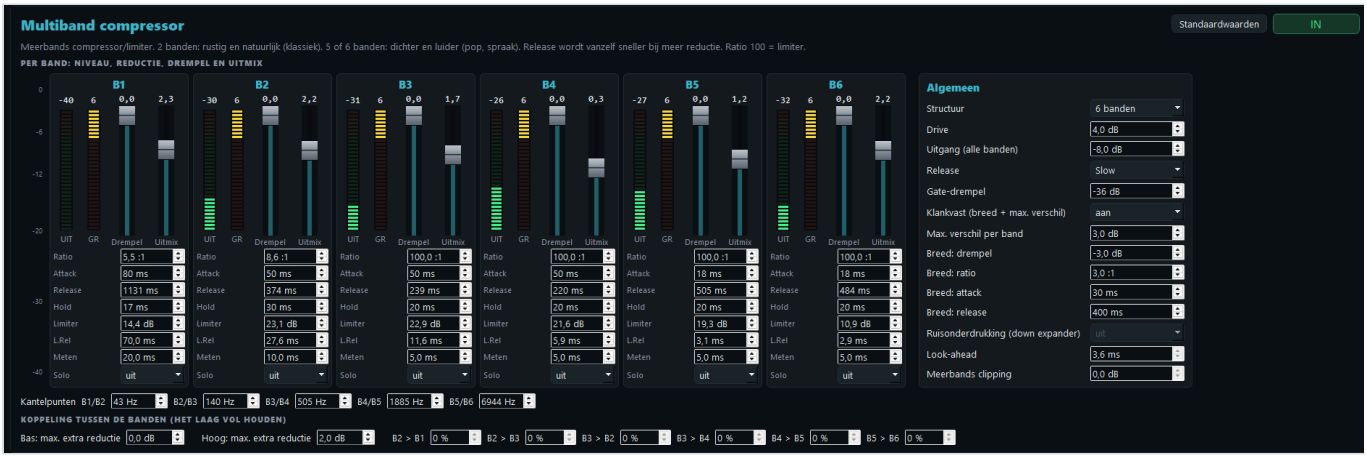
EQ (7 bands)

A parametric equalizer with 7 bands. It sits before the compressor: what you add here is kept neatly in check afterwards.

Control (per band)	Range	Explanation
Soort (type)	uit, piek, low shelf, high shelf (off, peak, low shelf, high shelf)	Peak = a bump or dip around the frequency. Shelf = everything below (low) or above (high) the frequency.
Frequentie (frequency)	15 to 15000 Hz	Default 60, 150, 500, 1500, 4000, 10000 and 12000 Hz.
Versterking (gain)	−12 to +12 dB	Also with sliders 1 to 7 on the meter bridge.
Breedte (width)	0.3 to 4 octaves	Narrow = precise, wide = soft and musical. For a shelf: how steep.

> **Advice.** Less is more. 1 to 3 dB is usually enough. If you want more bass, look at the Sub first. If you want more clarity, use a high shelf of 1 to 2 dB around 8 to 10 kHz.

Multiband compressor



The multiband compressor with 6 bands: per band meters, threshold, output mix and the times; on the right the general controls.

This is the heart of the processor. The audio is split into bands, from low to high. Each band has its own compressor. That way a loud kick drum cannot pull the highs down. The result: dense, even and loud.

Algemeen (general)

Control	Range	Default	Explanation
Structuur (structure)	2, 5 or 6 bands	5	2 bands: calm and natural (classical, speech). 5 or 6 bands: denser and louder (pop).
Drive	0 to 25 dB	10	How hard the audio goes into the compressor. More drive = more reduction = denser.
Uitgang (alle banden) (output, all bands)	−18 to +6 dB	0	The level after the compressor.
Release	Slow, Slow2, Med, Med2, MFast, MFast2, Fast	Med	How fast all bands let go. Faster = louder, but you hear it "pumping" sooner.
Gate-drempel	−44 to −15 dB	−36	In silences the compressor holds its setting. Then the noise does not come up.
Kantelpunten (crossover points)	30 to 12000 Hz	150, 420, 1000, 3700, 6200	Where the bands meet.

Klankvast (fixed tone)

A normal multiband changes the tone as it gets louder: each band presses differently. Klankvast prevents that. A wideband compressor sets the reduction for all bands together. Each band may only differ from that a little. That way the tone stays the same, soft or loud.

Control	Range	Default	Explanation
Klankvast	uit, aan (off, on)	on	Recommended: on.
Breed: drempel (wide: threshold)	−24 to +12 dB	−3	Where the wideband compressor starts to work.
Breed: ratio (wide: ratio)	1 to 100	4	How hard it presses. 100 = limiter.
Breed: attack (wide: attack)	1 to 500 ms	30	How fast it acts.
Breed: release (wide: release)	20 to 3000 ms	400	How fast it lets go.
Max. verschil per band (max. difference per band)	0 to 12 dB	3	How much extra a band may press. Small = fixed tone, large = each band more its own way.

Per band (B1 is the lowest, B6 the highest)

Control	Range	Default	Explanation
Drempel (threshold)	−24 to 0 dB	−6	Where the band starts to press.
Ratio	1 to 100	100	How hard. 100 = limiter. For the lows, 5 to 10 sounds more natural.
Attack	1 to 1000 ms	15	How fast the band acts.
Release	20 to 2000 ms	300	How long it takes to let go 10 dB.
Hold	0 to 500 ms	20	Hold for a moment first, then let go. Against "flapping" in the lows.
Limiter	0 to 24 dB	12	A fast limiter per band, this many dB above the threshold. 24 = off.
L.Rel	1 to 200 ms	20	How fast that limiter lets go 10 dB.
Meten (measure)	0 to 20 ms	per band	Over how much time the band measures the level. 0 = on the peak. Lows longer, highs shorter.
Uitmix (output mix)	−6 to +6 dB	0	How loud the band comes back into the mix. This is your tone control after the compressor.
Solo	uit, solo (off, solo)	off	Hear only this band. Handy while setting up.

Keeping the lows full

Control	Range	Default	Explanation
Bas: max. extra reductie (bass: max. extra reduction)	0 to 12 dB	6	The lows may press at most this much more than B2. 0 = off.
Hoog: max. extra reductie (high: max. extra reduction)	0 to 12 dB	2	The highs may press at most this much more than B4. That way the highs do not go dull as it gets louder.

> **Advice for the times.** A good start is: attack B1 80 ms, B2 50 ms, B3 and B4 50 ms, B5 and B6 15 to 20 ms. The highs must be able to act fast, or a sharp S slips through. The lows can be calm, or the bass distorts.

Grey controls in this panel (noise reduction, look-ahead, multiband clipping and the coupling between the bands) do not work yet.

Sub

The sub adds deep bass, below about 40 Hz. That gives the transmitter "body" without the normal bass booming.

Control	Range	Default	Explanation
Sub (Level)	0 to 20 dB	0 = off	How many dB of deep bass is added. The Sub meter on the meter bridge shows exactly that number.
Sub max	0 to 20 dB	20	The upper limit. If the sub goes above it, it turns back very gently. That way a track that already has a lot of bass stays within limits.
Sub-plek (sub position)	voor de eindlimiter, voor de clipper (before the final limiter, before the clipper)	voor de eindlimiter	Where the sub is added.

> **Advice.** Start with 3 to 6 dB and a Sub max of 5 to 8 dB. Listen on a radio with a good loudspeaker. Too much sub costs deviation and so loudness.

HF limiter (against sizzle)

After the pre-emphasis, FM lifts the highs a lot. A loud S or a hi-hat can then go into the clipper and start to sizzle. The HF limiter looks at the highs as they will be after the pre-emphasis. If that goes over the threshold, **only the highs** above the split point go down. It sits after the multiband and the sub, just before the final limiter. There is no delay.

Control	Range	Default	Explanation
Drempel (na pre-emphasis) (threshold, after pre-emphasis)	−40 to +6 dB	−4	Lower = acts sooner. Around −30 dB is good for modern, sharp music.
Splitspunt (split point)	2000 to 10000 Hz	8000	From here the highs go down. Around 9500 Hz you catch the S and the hi-hat without it going dull.
Release	20 to 1000 dB/s	100	How fast it lets go.

> **Advice.** Does it sizzle? Set the split point to 9500 Hz and lower the threshold until it is gone. On the meter bridge the HF limiter should act 3 to 6 dB on a sharp S. If it goes dull, the threshold is too low.

Final limiter and clipper (Clipper step)

These two sit together in one panel. They catch the last peaks before the audio goes to the stereo coder.

The **final limiter** takes the peaks away, without delay. What is still left, the **clipper** clips off. The clipper works at 4 times the sample rate. That gives fewer harsh harmonics than plain clipping.

The ceiling of the clipper is **fixed at −6 dB**. With the drive you push more into it: it gets fuller, not louder. The output can never get louder than the ceiling. How loud it goes on air, you then set at the Output.

Control	Range	Default	Explanation
Eindclip drive (final clip drive)	−6 to +12 dB	0	How hard it goes into the clipper. More = fuller and denser, but also more distortion.
Eindclip soort (final clip type)	zacht, middel, hard (soft, medium, hard)	middel	How the clipper takes the bend. Soft sounds rounder, hard is tighter.
Eindlimiter drive (final limiter drive)	0 to 20 dB	13	How hard it goes into the final limiter.
Eindlimiter hold (final limiter hold)	0 to 100 ms	20	Hold first, then let go.
Eindlimiter release (final limiter release)	10 to 1000 dB/s	30	How fast it lets go.
Eindlimiter max. reductie (final limiter max. reduction)	1 to 12 dB	5	The most it takes away. The clipper does the rest.

> **Advice.** On the meter bridge: Limiter a few dB, Clipper now and then 1 to 3 dB. If the clipper clips a lot all the time, the sound gets harsh and tiring. Then turn the clipper drive back.

15 kHz

Band limiting at 15 kHz. FM stereo must not go above 15 kHz: above that sits the pilot at 19 kHz. Leave this step `IN`.

Output

Control	Range	Default	Explanation
Uitgangsniveau (output level)	−20 to +24 dB	0	The level to the stereo coder, and so the deviation.
Loudness-doel (meter) (loudness target, meter)	−24 to −5 LUFS	−9	Only for the meter: the line at Loudness.

10. As loud as possible within 200 kHz

Everyone wants a transmitter that sounds nice and loud and full. But an FM transmitter has a channel of **200 kHz**. Everything has to fit in it. If you go outside it, your neighbour suffers. This chapter explains how to get the most out of that channel, without distortion and without disturbing the neighbours.

First the terms

Term	Explanation
Deviation	How far the frequency swings back and forth. For broadcast FM, 75 kHz is the limit. More deviation = louder, but also wider.
MPX	The complete signal that modulates the transmitter: L+R (mono), the pilot, L−R around 38 kHz and RDS at 57 kHz.
Pilot	A 19 kHz tone that tells a radio it is stereo. Usually 9 % of the deviation (6.75 kHz).
RDS	The station name and text, at 57 kHz. Usually 2 to 4 kHz deviation.
MPX power (dBr)	The average power of the MPX, over 60 seconds. This is what you hear as "loudness". 0 dBr is the official limit; many broadcasters are well above it.
Peak deviation	The highest peak. It must not go above 75 kHz.

The secret: the **peaks** may not go higher, but the **average** may go up. The closer the sound sits against the 75 kHz, the louder. The compressor, the clippers and the composite clipper do that together.

How loud is loud?

MPX power	How it sounds
0 dBr	Clean, open, lots of dynamics.
+2 dBr	Solid, still very open.
+4.5 dBr	Most commercial broadcasters are here. Loud and full.
+6 dBr	The maximum this transmitter can reach cleanly. Above it, it starts to distort.

You see the MPX power in three places: the line `MPX-vermogen … dBr` on the rack, the **MPX** meter on the meter bridge (F and S), and the **MPX-vermogen (BS.412)** box on the Modulatiemonitor. If it says "BS.412 te hoog" (too high), you are above 0 dBr. That is not a fault of the transmitter, but a warning.

The three tools

Tool	Where	What it does
Composite clipper	Modulatiemonitor: `Comp. clip aan` (comp. clip on) and `dB drive` (also on the Stereo coder tab)	Clips the peaks of the audio part of the MPX (L+R and L−R), **before** pilot and RDS are added. The clipping products near the pilot and near RDS are filtered out. That way the audio part can go louder without making pilot and RDS dirty. This gives the most dBr.
MPX clipper	Modulatiemonitor: `Clipper aan` (clipper on), limit in kHz and knee in dB	The last safety: whatever goes above the limit does not go out. It sits just before the FM modulator.
Channel filter	Always on, fixed at 200 kHz	Removes everything outside the channel. Next to your transmitter it is then quiet.

Step by step

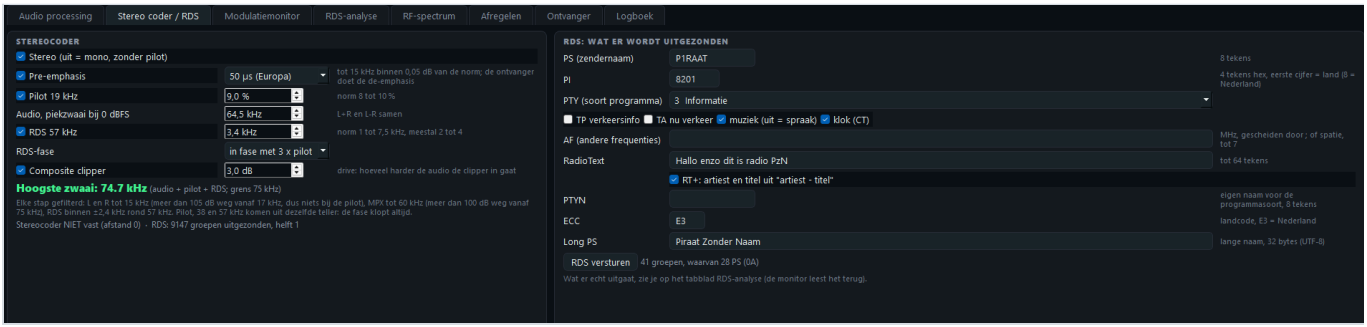
1. **MPX clipper.** `Clipper aan`, limit **73 kHz**, knee **1.5 dB**. The channel filter makes the peaks about 2 to 4 kHz higher. With 73 kHz you then end up just at 75 kHz. A small knee is important: a large knee rounds off the whole MPX, the pilot too, and then the gap around 19 kHz fills up with junk.
2. **Stereo coder.** Pilot 9 %, RDS around 3 kHz, pre-emphasis 50 µs (in Europe). See chapter 11.
3. **Choose a preset** as a start, for example `PzN-Radio` (chapter 16).
4. **Play solid music.** On the Modulatiemonitor, watch the peak deviation. Turn the `Uitgang` (output) in the processor until the peak deviation is around 70 to 75 kHz and the CLIP lamp now and then shows a few dB.
5. **Composite clipper.** Switch on `Comp. clip aan`. Start with 2 dB drive. Turn the drive up half a dB at a time and watch the MPX power (S, over 60 seconds). Listen in between. If you hear distortion, go one step back.
6. **Sizzle?** HF limiter on, split point 9500 Hz, threshold around −30 dB.
7. **Fuller?** More clipper drive in the Clipper step, or more drive in the multiband. But every extra dB is also more distortion. Listen.
8. **Check the neighbours.** On the RF-spectrum tab everything must stay within the 200 kHz lines.
9. Happy? Save it as your own preset. The composite clipper and the MPX clipper are saved along with the preset.

> **Note.** Louder is not always better. From about +6 dBr the sound gets harsh, tiring and distorted. Always listen on a normal radio, not only to the meters. And stick to the limits of your licence: on the amateur bands there are separate rules for bandwidth.

What to watch while setting up

Meter	Where	Good
Peak deviation	Modulatiemonitor, big number	Around 70 to 75 kHz, not above. The ITU peak below it should stay around 75.
MPX power	rack, meter bridge (MPX), Modulatiemonitor	The target you choose, for example +4.5 dBr.
CLIP	rack	Now and then a few dB. Not a lot all the time.
Pilot and RDS	Modulatiemonitor	Pilot 9 %, RDS on your target. They must stay steady, even with loud music.
MPX spectrum	Modulatiemonitor	A clean gap around 19 kHz (the pilot stands alone in it). Above 60 kHz only the RDS bump and noise.
RF spectrum	RF-spectrum	Everything within the 200 kHz channel.

11. Stereo coder / RDS tab



The stereo coder (left) and what is sent in RDS (right).

Stereo coder

Control	Range	Default	Explanation
Stereo	aan, uit (on, off)	on	Off = mono, without pilot.
Pre-emphasis	50 µs (Europa), 75 µs (VS) (Europe, USA)	on, 50 µs	The highs are lifted; the radio turns them back down. That gives less noise.
Pilot 19 kHz	6 to 12 %	9 %	8 to 10 % is usual.
Audio, piekzwaai bij 0 dBFS (audio, peak deviation at 0 dBFS)	20 to 75 kHz	64.5 kHz	How much deviation the audio gives at full level (L+R and L−R together).
RDS 57 kHz	1 to 7.5 kHz	3.4 kHz	Usually 2 to 4 kHz.
RDS-fase (RDS phase)	in fase met 3 x pilot, kwadratuur (90°) (in phase with 3 x pilot, quadrature)	in phase	Leave it, unless a radio reads RDS badly.
Composite clipper	on, off; drive 0 to 6 dB	off, 2 dB	See chapter 10. The same control as `Comp. clip` on the Modulatiemonitor.

Every step is filtered. L and R up to 15 kHz, so nothing gets near the pilot. The MPX up to 60 kHz. RDS neatly around 57 kHz. Pilot, 38 and 57 kHz come from the same counter: the phase is always right.

RDS

Field	Explanation
PS (zendernaam) (station name)	8 characters, as the radio shows it.
PI	4 hex characters; the first digit is the country (8 = Netherlands).
PTY	Programme type.
TP, TA, muziek, klok (CT) (music, clock)	Traffic programme, traffic announcement now, music or speech, and the clock (once a minute).
AF	Alternative frequencies in MHz, up to 7.
RadioText	Up to 64 characters. With RT+, artist and title are recognised from "artist - title".
PTYN, ECC, Long PS	Own programme type (8 characters), country code (E3 = Netherlands), long name (32 bytes).

Press `RDS versturen` (send RDS) when you have changed something. What really goes out, you see on the RDS-analyse tab.

12. Modulatiemonitor tab

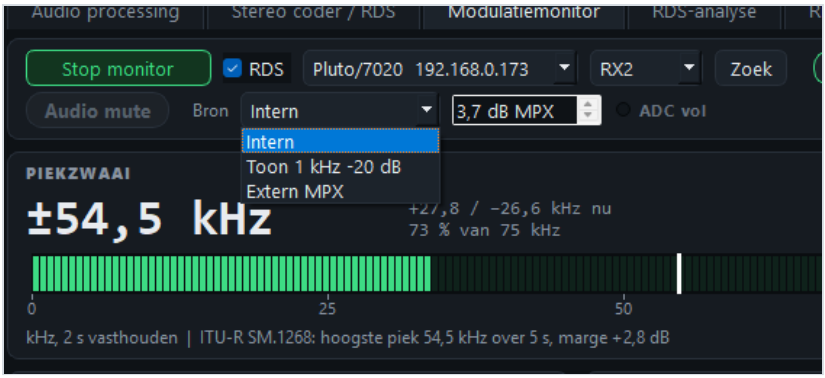


The modulation monitor: peak deviation, MPX power, pilot, RDS and the MPX spectrum. On the second line Audio mute, Bron, dB MPX and ADC OVERLOAD.

The monitor measures your own broadcast, through RX2 of the 7020 (or through a second SDR).

The bar at the top

Item	Explanation
Start monitor / Stop monitor	Starts or stops measuring.
RDS	Unticked: faster refresh, but then no RDS.
Bron en ingang (source and input)	Pluto/7020 with RX2 (recommended), an RSPdx or Demo.
Clipper aan	The MPX clipper. Limit 60 to 80 kHz, knee 0 to 6 dB. Recommended: 73 kHz and 1.5 dB. The lamp after it shows how many dB it takes off.
Audio mute	Music off, pilot and RDS stay on. Red = mute on. After a restart, mute is off.
Bron	**Intern** (internal): the processor. **Toon 1 kHz -20 dB** (tone 1 kHz −20 dB): mono 1 kHz at 7.5 kHz deviation, with pilot and RDS. **Extern MPX** (external MPX): the ADC (left) goes straight to the transmitter; set the level with `dB MPX` (start at -8 dB). The `ADC OVERLOAD` lamp turns red when the ADC hits full scale. The choice Intern or Extern MPX is remembered; the tone is not.
Comp. clip	The composite clipper on or off (green = on), with the drive in dB.
Labels	stereo, pilot, RDS with the station name, BS.412 and overstuurd (overdriven). Green is good.

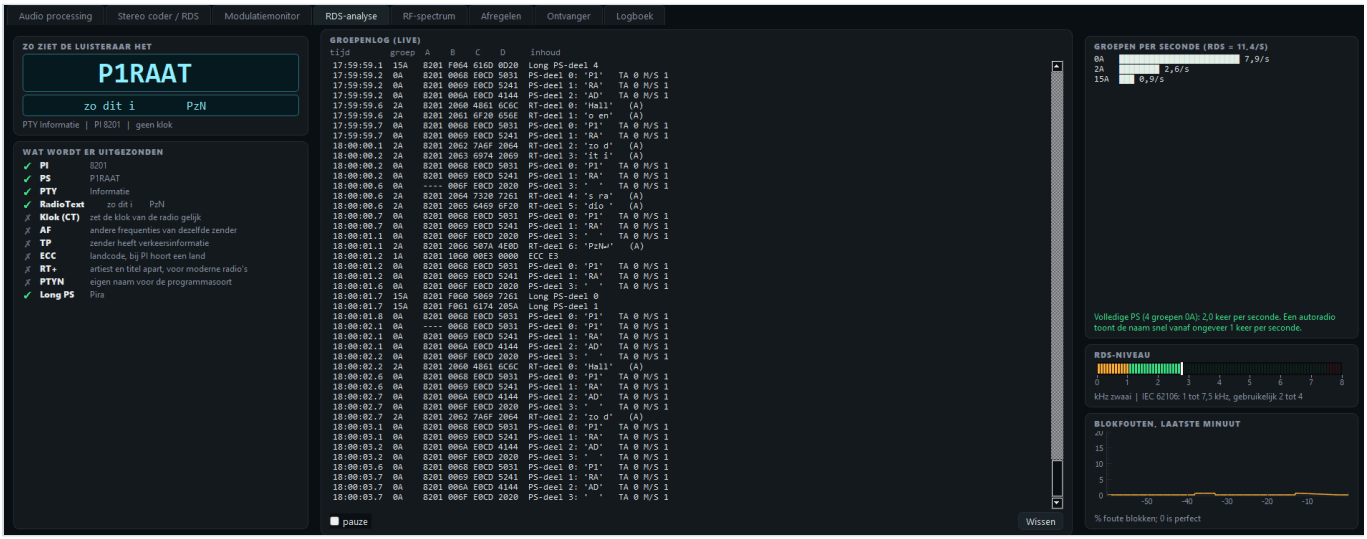


The Bron list: Intern, Toon 1 kHz -20 dB or Extern MPX.

What you see

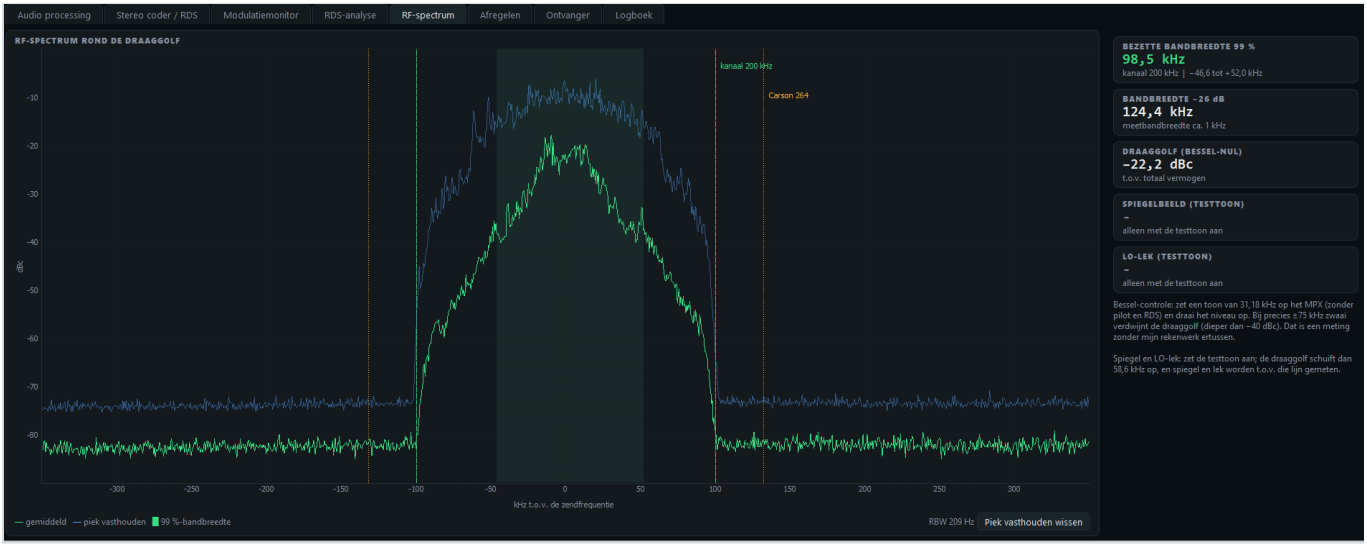
Box	Explanation
Piekzwaai (peak deviation)	The largest deviation, held for two seconds. Below it the highest peak over a longer time (ITU).
MPX-vermogen (BS.412)	The average over 60 seconds in dBr, and over the last second.
Pilot	Pilot deviation in kHz and percent, and the pilot frequency.
38 kHz-fase (38 kHz phase)	Must be around 0°. This sets the channel separation.
RDS-injectie (RDS injection)	The RDS deviation.
Draaggolf (carrier)	How far the carrier is off the set frequency.
Ontvangst (reception)	How strong the measuring signal comes in. Red = too strong: more attenuation.
Meters (orange line = target)	Deviation, pilot, RDS and MPX power, each with a target line. The number changes colour with how far off you are.
MPX-spectrum (MPX spectrum)	The MPX up to 100 kHz: L+R, the pilot, L−R around 38 kHz, RDS at 57 kHz.
Audio L/R	The levels after de-emphasis and the channel separation. Put a tone on one channel: the difference is the separation.
RDS	Station name, PI, PTY and RadioText as they come in.

13. RDS-analyse and RF-spectrum



The RDS analysis.

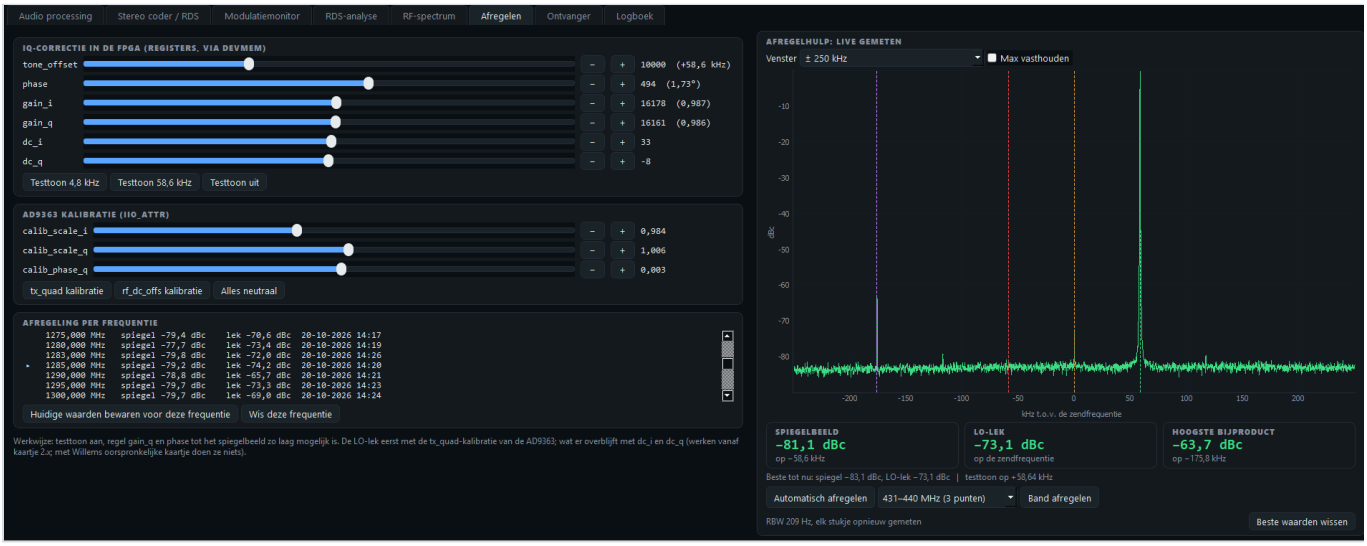
RDS-analyse reads back everything that is in the RDS: station name, RadioText, RT+, clock, AF list, groups per second and block errors. With good reception there are no block errors.



The RF spectrum around the carrier.

RF-spectrum shows the broadcast around the carrier. Green is the average, blue the held peak. The lines mark the 200 kHz channel. Here you see whether you stay within your channel. With `Piek vasthouden wissen` (clear peak hold) you start again.

14. Afregelen tab



Alignment: on the left the sliders and the list per frequency, on the right the alignment helper.

Why alignment

A transmitter like this always makes a little **image** (the signal mirrored on the other side of the carrier) and a little **carrier leakage**. How well that is suppressed differs per frequency. Alignment means: setting the sliders so that both are as low as possible.

How to connect

The 7020 measures its own transmitter. Connect TX1 through a 30 dB attenuator to RX2, and choose RX2 on the Modulatiemonitor. To transmit and measure at the same time, use a home-made splitter: three SMA sockets in a star, with 16.5 Ω in each leg.



Home-made splitter: three SMA sockets with three 16.5 Ω SMD resistors in a star. Each leg loses 6 dB.

Automatic alignment

1. Connected, monitor on, transmitter on.
2. Click `Automatisch afregelen` (automatic alignment).
3. The program switches the test tone on, lowers the power if needed and finds the best setting for each slider: coarse first, then fine.

4. The result is saved with this frequency. Power and test tone go back.

With `Band afregelen` (align band) it aligns a whole band, every 5 MHz (431 to 440, 1240 to 1300 or 2340 to 2400 MHz). It does three rounds per point. That takes a while. Each point is saved at once.

The list per frequency

Each aligned frequency goes into the list, with the measured image and leakage and the date. When you choose a frequency, the program puts the alignment of the nearest frequency in the list on the 7020.

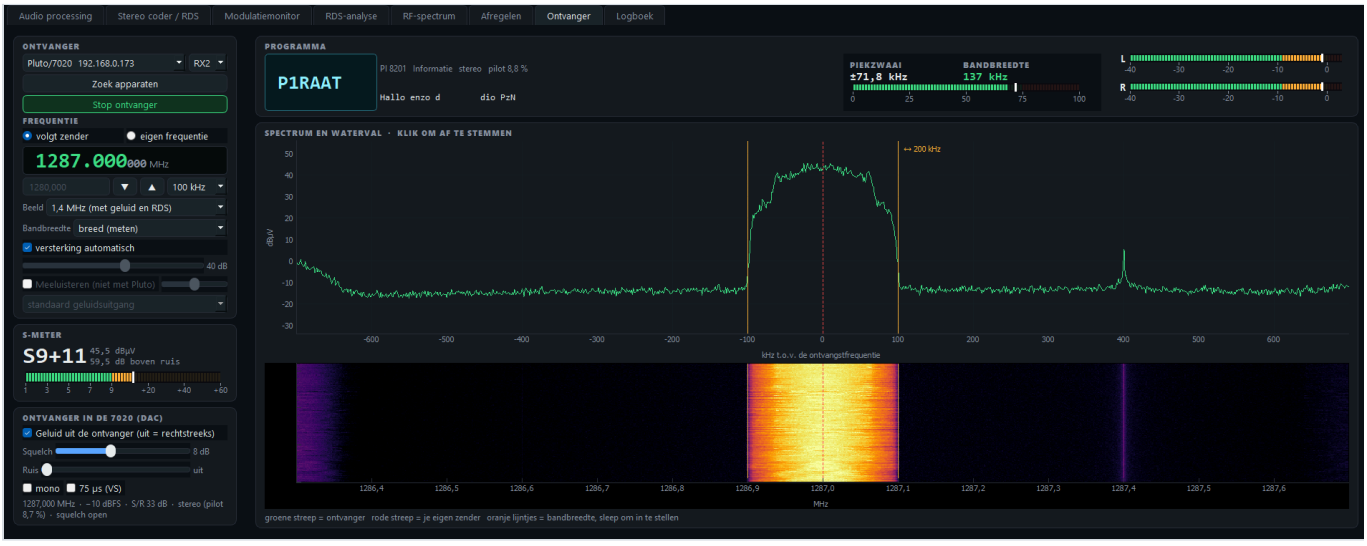
> **Aligning once is enough.** The AD9363 also aligns itself, again at every start-up, and each time a bit differently. That is why the program switches off the chip's own alignment, and saves the chip's state in the list too. After off and on again, everything is exactly as you saved it. A frequency you aligned earlier with an older version, you align once more.

Manual alignment

1. Transmitter on, monitor on.
2. Switch on `Testtoon 58,6 kHz` (test tone 58.6 kHz).
3. Turn `gain_q` and `phase` until the image is as low as possible.
4. Turn `dc_i` and `dc_q` until the carrier leakage is as low as possible.
5. Click `Huidige waarden bewaren voor deze frequentie` (save current values for this frequency).
6. Test tone off again.

The `tx_quad kalibratie` (tx_quad calibration) button lets the chip align itself. On this transmitter that usually makes it worse. Only use it to try, and do not save afterwards if it is worse.

15. Ontvanger tab

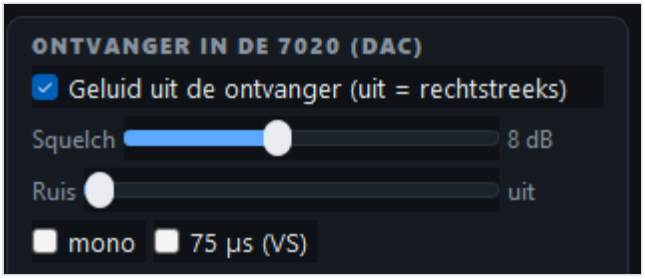


The receiver: spectrum and waterfall (click to tune), S meter, station name and RadioText.

A second receiver to look at other stations, with spectrum, waterfall, S meter, station name and RadioText. Click in the spectrum or turn the mouse wheel to tune.

Bandbreedte (bandwidth): `breed (meten)` (wide, measuring) or the same steps as a TEF receiver, from 287 to 114 kHz. With ◀ and ▶ one step narrower or wider, or drag the orange lines. The choice also applies to the receiver in the 7020; that one has three filters: wide up to 217 kHz becomes 300 kHz, 200 kHz becomes 210 kHz, 184 kHz and narrower becomes 190 kHz. RX1 or RX2 applies to monitor and receiver together.

Ontvanger in de 7020 (receiver in the 7020, DAC)



The Ontvanger in de 7020 card: audio from the receiver, squelch, noise, mono and 75 µs.

The FPGA holds a complete FM receiver: stereo, de-emphasis and squelch. The audio goes straight to the DAC board. Transmitting and receiving work at the same time.

Control	Range	Explanation
Geluid uit de ontvanger (audio from the receiver)	on, off	On: the DAC plays the receiver. Off: the DAC plays the audio straight from the processor.
Squelch	off to 20 dB	Below this signal-to-noise ratio the audio closes softly. A few dB is usually enough.
Ruis (noise)	0 to 10	Noise reduction. 0 = off. 1 to 5: stereo gradually goes to mono (less noise, the highs stay). 6 to 10: on top of that the highs also go down gradually. Set it as low as you can.
mono	on, off	Always mono.
75 µs (VS) (USA)	on, off	De-emphasis for American stations.

If you listen to your own transmitter, you hear exactly what goes on air, with all processing on it. If you close the program, the DAC goes silent.

16. Presets

A preset is a complete processor setting, under one name. At the first start a few are ready.

What is in a preset

- all controls of all stages, and which stages are on or off;
- the composite clipper: on or off, and the drive;
- the MPX clipper: on or off, the limit and the knee.

A preset without clipper settings leaves the clippers as they were.

The supplied presets

Preset	Character
PzN-Radio	The all-round radio station of PE1PzN. Full lows, open highs, with the composite clipper on.
Doorverbinden (alles bypass) (pass-through, bypass all)	Everything off: the audio goes through unprocessed. Cannot be removed.

Every source and every recording is different. See the presets as a start. Then adjust by ear and save it under a name of your own.

The lock

The supplied presets are **locked**. You then see a small lock after the name. A locked preset cannot be overwritten or deleted. You may turn the controls; you then save under a different name.

- **Unlock:** choose the preset and untick `Slot`.
- **Throw away:** unlock, then `Verwijderen`. A supplied preset you throw away does not come back by itself.
- **Lock your own preset:** choose it and tick `Slot`.

Save, export and import

Button	What it does
Opslaan als…	Save the current settings under a name. A name that is locked is not possible.
Exporteren…	With ticks you choose which presets, and where the file goes. It becomes a `.json` file. Handy as a backup, or to give your setting to someone else.
Importeren…	Choose a preset file and tick which presets you want. If the name already exists, the program asks: `Ja` (yes) = overwrite, `Nee` (no) = add with a new name, such as "PzN-Radio (2)". A locked preset is never overwritten.

17. Troubleshooting

Problem	What to do
Zoek finds nothing	Wait until the 7020 has fully started (a good half minute). Try USB. Check that the firewall allows the program.
No audio in the broadcast	Is the ADC board connected and set to Master, 24 bit, 192 kHz? Is `Bron` set to I2S-ingang? Does the Input meter move?
ADC over lamp	The source is too loud. Turn it down, not the Ingangsniveau.
No audio from the DAC	Check what is chosen under `DAC`. Check the FMT jumper of the DAC board.
It sizzles	HF limiter on, split point 9500 Hz, threshold down until it is gone. Faster attack in B5 and B6.
It distorts	Less composite clipper drive, less clipper drive, or choose a slightly lower MPX power.
It pumps	Slower multiband release (Slow or Med), less drive.
Junk around the pilot in the MPX spectrum	Knee of the MPX clipper at 1.5 dB. Step 15 kHz on IN.
Peak deviation above 75 kHz	Limit of the MPX clipper half a kHz lower, or the Uitgang down a bit.
Image or leakage worse after off and on	Align the frequency once more and save (chapter 14).
Change in the FPGA not active after restart	A restart of Linux does not reload the FPGA. Remove the power for a moment.

18. Disclaimer

> **Only for radio amateurs and radio research, not for commercial use.** The program, the files for the SD card and this manual are given free of charge as they are, without any warranty. Use is at your own risk: PE1PzN is not liable for damage to equipment, interference to others or any other result of its use. You may only transmit within the terms of your own licence and on frequencies where you are allowed to; that is your own responsibility.