HF-DR series

High Stability RF Generator
for Ion Traps and Quadrupole Structures

HF-DR_PaulDrives_Manual3_32.doc
December 2023

Datasheet
Rev. 3.32

Model HF-DR

Main Features:

- high voltage RF drive
- amplitudes up to 3000Vpp
- frequency 1MHz up to 40MHz customizable
- ultra stable (ppm-level) output for ion clocks, quantum computing

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Purpose and Description of the Device

HF-DR series drives provide AC voltages to Paul Ion Traps and other Quadrupole-type electrode setups for ion storage and manipulation. Unlike standard RF (radiofrequency) generators and power amplifiers, the device is capable to handle significant capacitive loads, which are related to vacuum setups for ion trapping.
Importantly, the device can stabilize the output amplitude at a highly accurate level (up to 3ppm over one minute) using dedicated stabilization loops. This greatly eases applications like ion clocks or quantum computing.
Depending on the model variant, one or two outputs are installed, in the latter case they differ by 180°, thus effectively doubling the voltage seen by a trapped particle. The HF-DR device is designed to deliver voltages up to 900V_{pp} AC at frequencies typically between 1.0MHz and 8MHz into a 20pF to 80pF load on each output, i.e. in case of two outputs max. 1800Vpp (differentially, low capacitive load), eventually up to 3000Vpp at lower frequencies, depending on device options. Customized versions around ~16MHz or ~40MHz are feasible.

This generator is housed in a standard 19-inch rack-mount case and features a remote control feature, by which the user can control the device via a standard USB connection.
Optionally, the device features a fast *turn-off* circuit, to release the stored particles quickly out of the trapping volume by damping the output resonator, within one oscillation period.

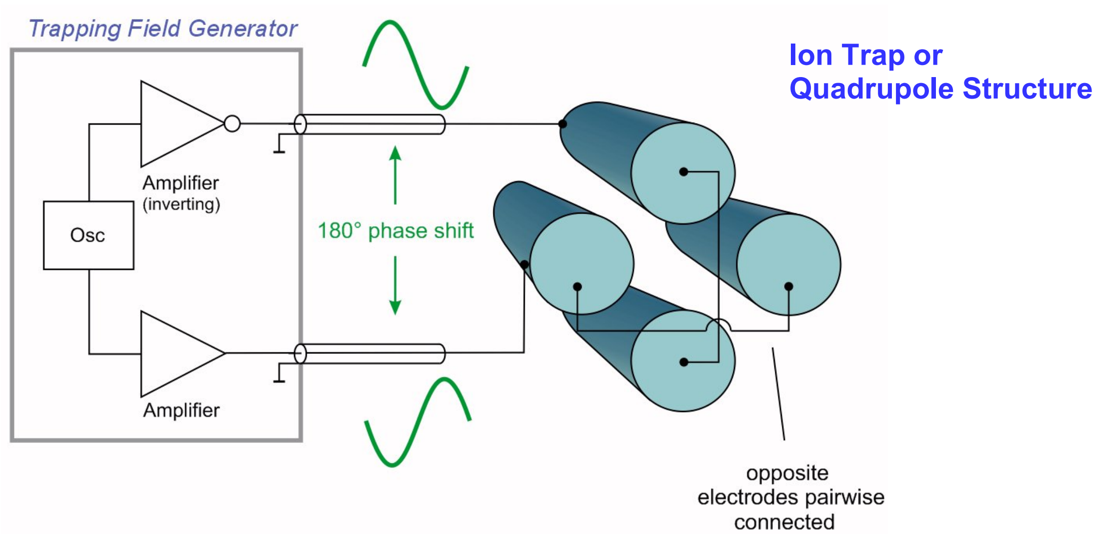

Fig. 1: Typical RF drive application: supply of Paul Traps or RF Ion Guides. The twin output doubles the effective voltage due to the 180° phase shift.

Device Nomenclature and Parameter Range

Example: HF-DR 3.5 - 900 FL

- FL └ Floating Coil option
- 900 └ nominal output voltage (peak-peak, Volts) each channel, i.e. double value, 1800Vpp *between* the output channels
- 3.5 └ nominal center frequency in MHz

The device is available as single channel version, dual channel (0°,180°) and dual channel with 'Floating coil' option'FL'. The (differential) amplitudes range between 500Vpp to 1800Vpp (max. 3000Vpp), depending on model, with center frequencies between 1.0MHz to 8MHz at typically 50pF load each channel (not all combinations are available, please contact manufacturer).

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Functional Principle and Block Diagram

The following picture (fig. 2a) displays a block diagram of the internal structure, illustrating the functional principle. A digital oscillator provides a sine wave of freely adjustable and precise frequency. An inverter circuit creates the inverted signal, or in other words a 180° shift. These two signals are fed into power amplifiers of adjusted amplification factor, followed by a resonant circuit. The latter steps up the obtainable voltage (about 20Vpp out of the power amplifier, PA) roughly by a factor of 50 to 100. Thus, voltages of a few hundred volts to about 2kV (peak-peak values) are created, suited for Paul Ion Traps or Quadrupole Structures. For balancing possible asymmetries, trim capacitors are provided (rear side) to balance different capacitive output loads, thus obtaining equal output levels on both outputs.
The device features an offset DC input, by which the output voltages can be shifted DC-related. Voltages being applied to these input lines are added to the AC signal (RF) of the outputs (this feature is not shown in fig. 2a/b). This also applies for multiple DC offset, e.g. for linear quadrupole or octupole structures.
Optionally a fast turn-off feature can be installed. This can swiftly damp away the energy in the output resonator, reducing the amplitude within less than one oscillation period close to zero.
The USB section allows for remote control of essential functions of the device via a standard USB connection. Please refer to control elements on front plate in next chapter and command syntax for remote control in the appendix.

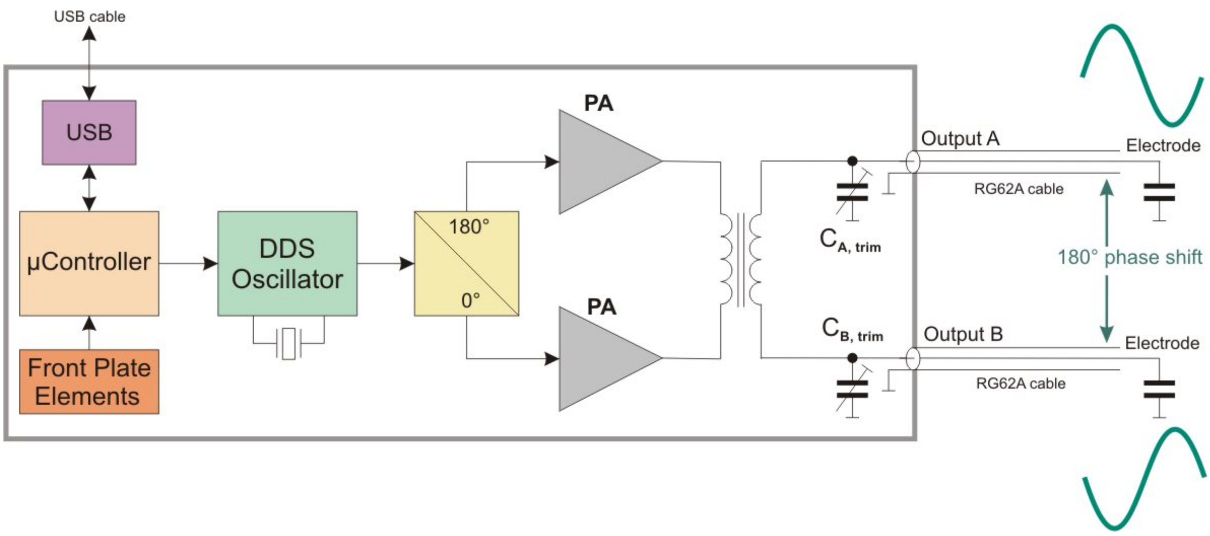

Fig. 2 : Block diagram of the internal structure, illustrating the functional principle.
For simplicity, the amplitude regulation loops and fast-turn-off circuitry are not depicted.

Safety Hints

Risk of electrical shock	This device can produce high voltages at its output lines, which are harmful and dangerous in case of direct touch with the human body. Voltages may be even exceeded, in case that an additional external offset voltage is applied to the respective input. Care must be taken to avoid unintentional touching of any output line, and also if the device is brought into contact to any other device which might be endangered by high voltages. **Operation of this device is admissible only for qualified personnel.**
Read all installation, operation, and safety instructions	Prior to operation, thoroughly review all safety, installation, and operating instructions accompanying this equipment.
Rear side switch turns device completely off	If the device is not in use for a longer time, it is recommended to turn the mains switch at rear side off.
This equipment must be connected to an earth safety ground	This product is grounded through the grounding conductor of the power cord. To avoid electrical hazard, the grounding conductor must be connected to protective earth ground.
Do not modify the unit	Do not make electrical or mechanical modifications to this unit.
Change cabling only when device is off	Changing the cabling, when voltages are present at the outputs can lead to formation of harmful sparks.
Do not operate in wet/damp conditions	To avoid electric shock hazard, do not operate this product in wet or damp conditions. Protect the device from humidity and direct water contact.
Beware of external magnetic fields	External magnetic fields can impair, damage or even destroy this device. A maximum external field strength of no more than B = 5mT is admissible. Having placed the device at any time into an external magnetic of bigger B = 5mT (regardless, if power was turned on or off) can lead to severe overheating of the device and severely increased hazard of fire.
Service is to be performed by qualified service persons only	All servicing on this equipment must be carried out by factory-qualified service personnel only.
Do not block chassis ventilation openings	Slots and openings in the chassis are provided for ventilation purposes to prevent overheating of the equipment and must not be restricted. All case vents should continuously be cleared, in order to prevent overheating. If in doubt about the sufficiency of air ventilation, provide a software readout of the internal temperature sensor for regular inspection, e.g. every 2 minutes. A temperature over 55°C indicates inadequate air ventilation.
Routinely cleaning from dust	After long operation, or operation in a dusty environment it is strongly recommended to have the internal parts of the device cleaned by the manufacturer, or an appropriately qualified workshop in order to reduce the hazard of overheating.
No outdoor operation	Outdoor operation of the device is not admissible.

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Operation and Control elements

Mains Supply Switch | LCD Display | Phase Output | Activate/ Deactivate Switch | Control Keys | Excitation Input

The front plate contains the main control elements of the device:

Mains Supply Switch

The device is powered up after activating the rear-side mains supply switch and switching the power button on the front plate into the "on" position. A Power-on-LED (green) indicates proper operation of the internal circuitry. A warning beeper will temporarily sound, which is used for ventilation fan-speed monitoring. If the warning beeper permanently sounds, the device must not be put into operation. In general, if the device is not in use for a longer time, it is recommended to deactivate the rear side mains switch to cut the device completely off from mains supply. This is mainly for safety reasons.

Phase Output

The HF-DR devices feature an internal precision oscillator, which provides a logic level (i.e. 0V / 5V, rectangular signal) to monitor the oscillator's phase. This output is helpful e.g. in case of an ion extraction out of the trap and exact timing with small jitter (< $0.6ns_{rms}$) is required. External triggers or pulse generators may be connected to this output therefor.
Optionally, this output is synchronized to the BNC input for deactivating the output (see appendix).

Activate/Deactivate Switch

This input allows for activating and deactivating the output amplitude of the device. It may be operated
- manually with the switch on the front plate plate
- remotely via USB connnection or
- using the logic level being applied to the BNC input socket (left open: activated)

A low level at the BNC input socket here deactivates the RF power, high level activates it.
For safety reasons the manual switch position, being switched to 'off' overrides other settings.
In case the optionally available **fast-turn-off feature** is installed, the output waveform is terminated in very short time (see chapter below), e.g. for ion ejection out of an ion trap.
In general, a deactivation of the output signal should not happen at a too frequent repetition rate. A rate of no more than 5 Hz (i.e. cycling the output power 5 times per second) is recommended to maintain a long lifetime of the fast-turn-off switching unit. Note that optionally the fast-turn-off feature is synchronized to the internal oscillator phase to ensure the the turn-off switch is activated always at the same RF phase (see appendix).

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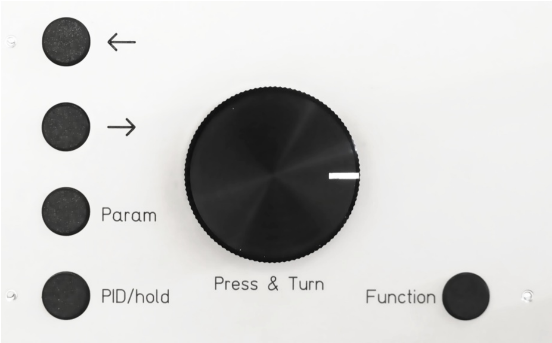
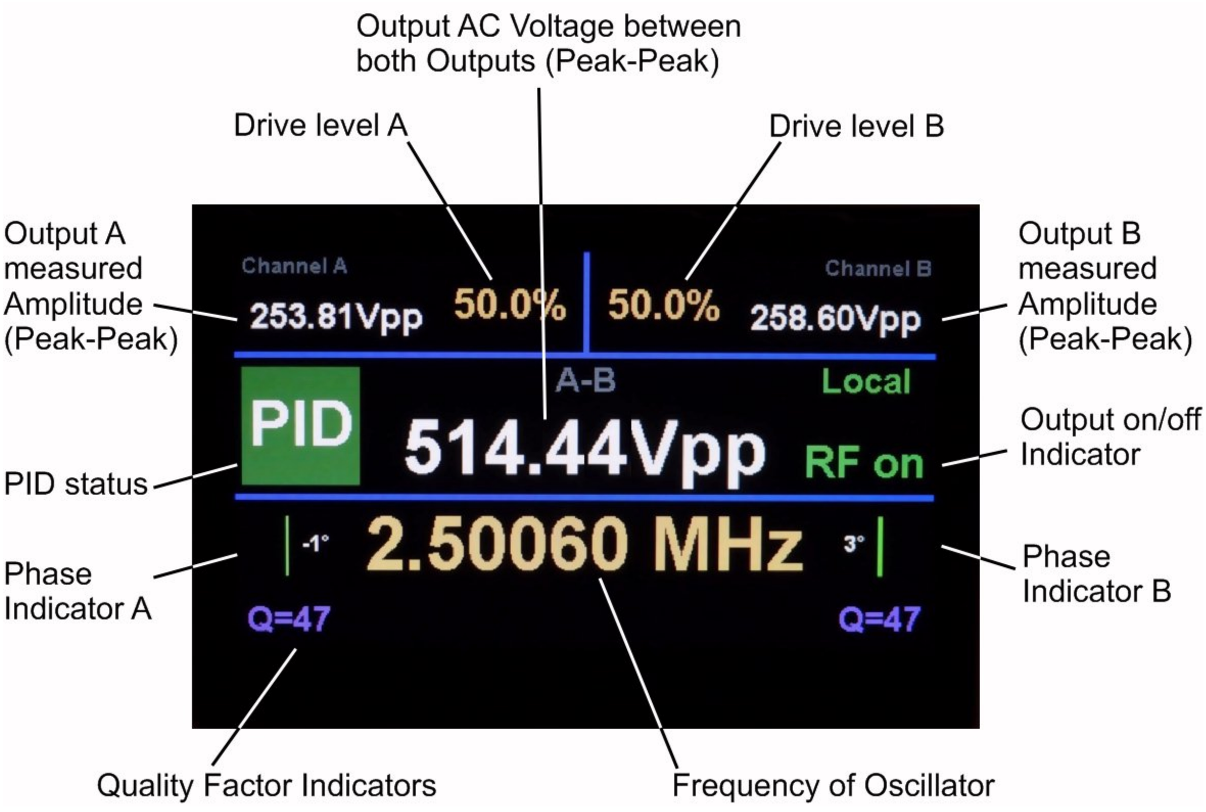
Control Keys



The device is manually operated by the control keys and selection wheel. Pressing the button 'Param' chooses the parameter to be changed, i.e. drive level for outputs A and B and the frequency. Arrows → and ← choose the digit to be changed. 'Function' is reserved for special functions and routinely toggles the device from 'manual' to 'remote mode'. In the latter the device is controlled via the USB bus interface by a PC, and manual entries are locked out.
For 'PID/Hold' function see below.



LCD Display

The LCD Display shows the main functions and parameters of the device, like chosen drive level, selected frequency, PID status. The display reduces light intensity after 60 minutes to prolongate its lifetime. For general operation of the device see below (picture above shows display of the Dual-Channel version). The details of display contents may differ slightly on the model version.

Excitation Input

If this option is installed, the excitation input allows for adding a small voltage difference to one of the RF outputs. This serves for creating an additional (quadrupole) component e.g. for ion excitation. The transfer function, i.e. the response of the output line upon applying a signal on the BNC input on the front panel is shown below. This voltage is linearly superposed to the RF field. A voltage up to 10Vpp (20Vpp for short durations) may be applied here. The LED indicator on the pront plate has a gradual onset above approx. 3.5Vpp voltage.

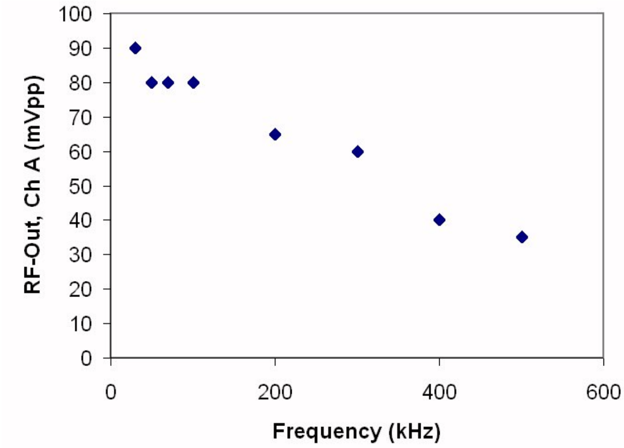


fig. 3 transfer function from excitation input to channel A (measured at device with serial number 016010), 20Vpp being applied at corresponding BNC input.

Basic Device Operation

As the device represents a *resonant* amplifier, it needs to be manually frequency-tuned to the specific experiment. Therefor, it is recommended to firstly complete wiring to the Ion Trap (or Quadrupole Structure). Make sure there are no shortcuts and connect to the device using appropriate cabling (normally coaxial cables), which can sustain the voltages and which protects from unintentional touching. In case of an external resonator box (applies for frequencies above approx. 8MHz), connect the latter correspondingly.

In order to start operation, put the 'Activate/Deactivate Switch' to the 'enable' position (regarding output Option FL, see also below). The display should show 'RF on' now. Increase the drive level (by pressing the 'Param' button and turning the selection wheel) to about 50% for each channel. The amplitude indicators should start to show some amplitude value now. Press the 'Param' button to select the frequency settings (cursor blinking) and **optimize the observed amplitude to its maximum carefully by tuning the frequency.** One may select e.g. the 10kHz digit and move the selection wheel by hand carefully to the left or to the right (lower or higher frequency) to search for increasing output voltage reading. In case both partial amplitudes on outputs A and B are substantially different one may also use the trim capacitors at the rear side of the device. These trim capacitors are meant for balancing parasitic capacitances on the output lines, or connected Ion Trap trap respectively to obtain equal output levels on outputs A and B. Subsequently optimize *again* the oscillator frequency to obtain maximum amplitude and eventually trim again an eventual unbalance.
Note, that after increasing the amplitude drive level to high values (larger 60%) one may need to tune again the frequency settings after some while (15 minutes) to account for temperature drifts in the coil resonance.

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In case a phase monitor is installed (this does not apply for the floating coil option 'FL') one can check whether the set frequency is too low or too high while looking at the phase indicators. They start to show a value once the amplitudes on the output channels are above 20Vpp approximately. If the indicated phase is below zero, decrease the frequency, otherise inecrease it. Alternatively, the trim capacitors can be used to change the resonance frequency. Increasing the trim capacitor value (turn to 'max cap') will lower the resonance frequency, otherwise (turn towards 'min cap') will increase it. Note that the trim capacitor knobs on the rear side of the device have a 180° turning range, the trim range is approx. 40pF. Note that the trim capacitor knobs have no fixed endpoints, please check their labelling for their min./max. capacitance position.
After both channels are well tuned (phase error about 5° or smaller or equal amplitude in case of option 'FL') one may further increase the amplitude by increasing the drive levels to their maximum values (typically 1800Vpp to 2200Vpp, or higher, if customized). In case the output amplitudes become too high the device automatically set the drive levels back to lower values, this maximum amplitude may be customized, see the remote control / command list section for details. However, be careful while increasing the drive levels, in order to protect the device and also circuitry and the experimental setup.
It is strongly recommended, not to operate the device higher than specified. Also, beware, not to operate the device for longer times (>30s) at high driver levels out of resonance, since overload/overtemperature conditions may result, which could be harmful for the device.
Note that a sudden drop of amplitude or phase change may indicate sparking (e.g. inside the attached vacuum setup/ion trap). In this case try to locate the problem immediately and avoid running the system close to the onset point of the problem to prevent damage by overheating or overvoltages.

Output Option FL

Most commonly, the output option FL is chosen, with a floating output coil (see fig. 2, which is the standard option in devices after production 12/2018) ensuring good symmetry of the 2 output signals, which can be important in certain ion trap setups. Without option FL a typical phase accuracy of 1° to 3° is achieved, and typical remaining amplitude asymmetry of 4% to 10%. The latter is limited by unavoidable coupling capacitances, which occur in quadrupole setups or ion traps and which are typically in the order of a few pF. They create a certain amount of unwanted coupling with the two output resonance circuits, thus making it impossible to adjust the amplitudes completely freely and individually. This can be a severe hinderance in cases, where very good symmetry of the two output signals is desired.
The output option FL avoids this problem, at expense of some loss of achievable amount of amplitude (about 20% less). In this case there is only one coil instead of two, repesenting only one resonance circuit.
The adjustment works as following: Set the output drive level to a certain value (e.g. 50%) and frequency at the desired value. Subsequently the settings of both output trim capacitors are adjusted: their setpoint *difference* defines the matching of output amplitudes, whereas their *combined* setting defines the resonance frequency and thus phase. Ususally one needs to adjust both, frequency/phase and amplitude matching in an iterative way: adjust output symmetry (bringing the number in the display center, above the letters 'A-B' close to zero), then frequency, again output symmerty etc. After approx. 5 to 6 iterations both phase (frequency) and amplitude matchings should be achieved. With this option FL a phase accuracy of 1 to 2° is typically achieved, and remaining amplitude asymmetry of less than 2%, in favor of minimizing micromotion heating effects of stored particles.

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Amplitude Stabilization *(PID loop)*

A special feature of the HF-DR series devices are high precision amplitude regulation loops, which are activated by pressing the corresponding PID/Hold button (press again to turn off again, or controlled via the USB interface). In the instance of activation, the current amplitude reading (A-B) of the differential amplitude between both outputs is captured and internally stored. Subsequently the drive levels of both channels are continuously adjusted in fine steps such that this differential amplitude value is kept constant. As consequence, the amplitude stability is greatly increased in comparison to free running systems. This can be advantageous for precision trapping experiments or experiments related to quantum computing to improve Qubit coherence.

Note that this option comes in two versions, a
- ***standard version*** with approx. **25 to 30ppm (rms) stability**
- and ***enhanced version*** with approx. **12 ppm (rms) stability** (option IS-12), which leads to a stability level of about 12ppm over seconds and 3ppm on a time scale of minutes.

As long as the regulation loop is capable of maintaining the differential amplitude value, the indicator will be green on the display, red otherwise.

The subsequent graphs depict examples of measured stability at half and full load conditions.

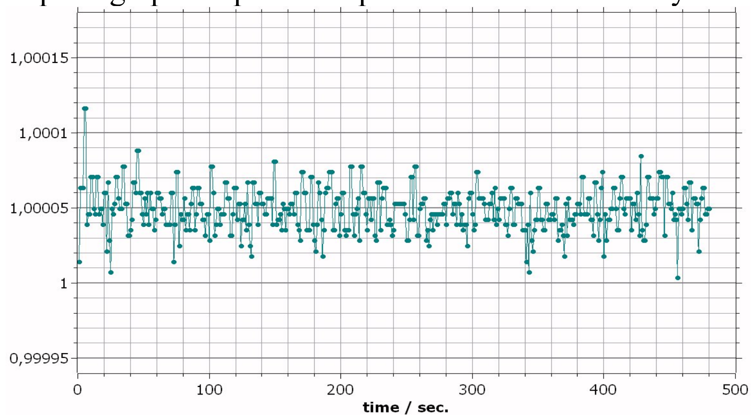

fig. 4a: **Standard version** PID, stability of output amplitude at medium output level (AC voltage difference between both outputs at 500Vpp) after PID is activated. Within a 8-minute interval the instability (relative amplitude deviation) is only on a level of 25ppm rms.

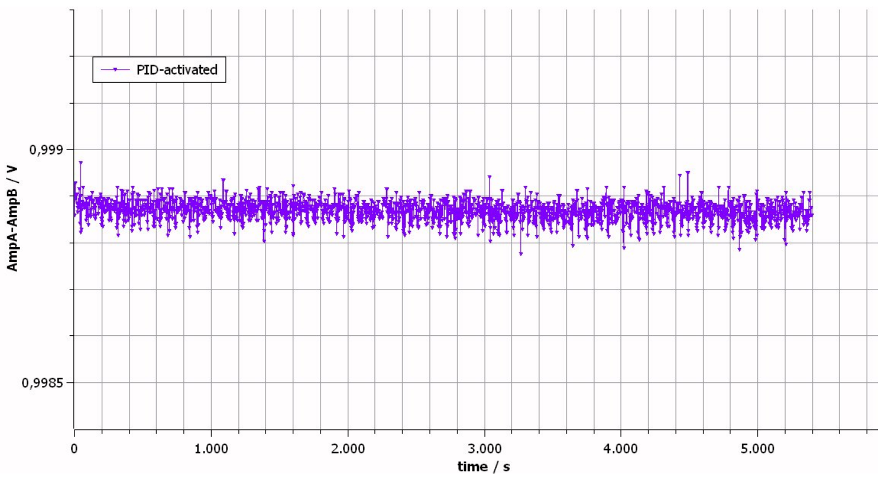

fig. 4b: **Standard version** PID, stability of output amplitude at full load (1800Vpp, approx. 80pF load), PID being activated. Within a 1-hour interval the remaining instability (relative amplitude deviation) is on a level of 30ppm rms with respect to the nominal value.

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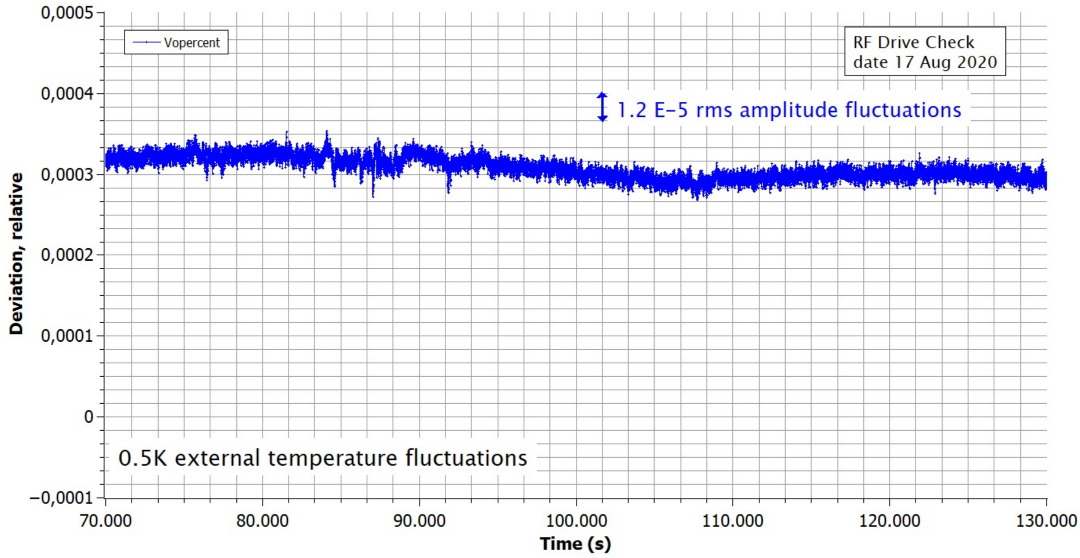

fig. 4c: **Enhanced version** PID (option IS-12), stability of output amplitude at full load (1800Vpp, approx. 40pF load), 15 hours depicted. On a time scale of hours the instability (relative amplitude deviation) is on a level of 12ppm rms. Diagrams above (figure a to c) refer to a typical output frequency between 1 and 4 MHz (higher frequencies see fig. 4f).

Start Up Behavior and High-Stability Mode

In general, all kind of amplitude sensors incorporate a certain degree of temperature dependent errors. In PID mode, the HF-DR series devices use highly precise temperature-compensated sensors to measure and stabilize the output amplitude. However, every temperature-compensated sensor still features a small but non-negligible residual error, which comes into play, when observation of amplitude changes on an extreme accuracy level in the ppm range take place. This is visible e.g. after a cold-start, if the PID is being activated after the output amplitude was completely different (or: zero) before. The following graph depicts the output amplitude (about 3.1kVpp), being measured with an external precision voltmeter, after the device has been started. It takes about 600 seconds (10 minutes), until the internal device sensors have stabilized on a deviation less than about 50ppm (i.e. 0.005%).

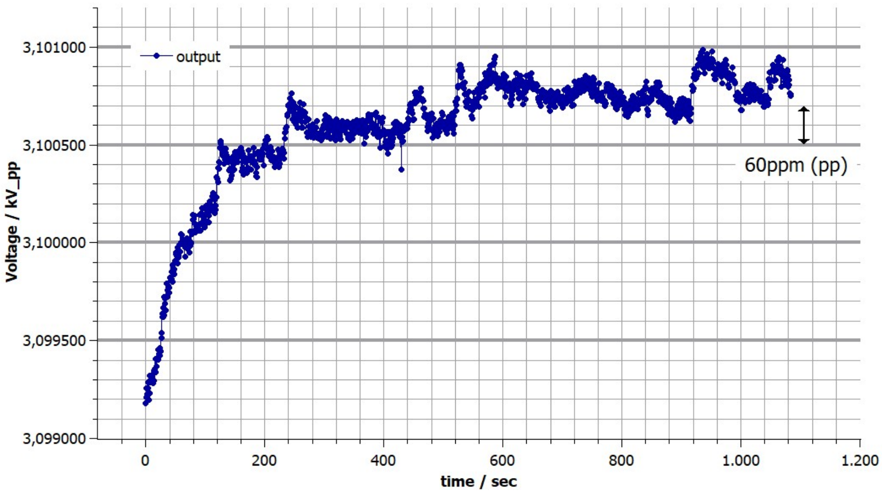

fig. 4d: Startup drift after cold start. After about 10 minutes the initial drift has ceased on a 50ppm level. After 10 minutes, the stability of output amplitude resides on a 60ppm to 70ppm level (about 25ppm in RMS terms) in case of standard version PID. Device: 1MHz, 3000Vpp, approx. 35pF load.

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As a consequence of these findings, one should allow about 10 to 15 minutes to pass by, after a cold start, or after the amplitude setting has been changed by a large amount, if compliance of the output level on a 50ppm scale is desired.

Stability Histogram

The subsequent graph depicts the probability distribution of output voltage values using 10sec averaging, in terms of deviation from the average of voltage over 1 hour. The RMS value of deviation amounts to about 25ppm rms. Standard version PID mode was used.

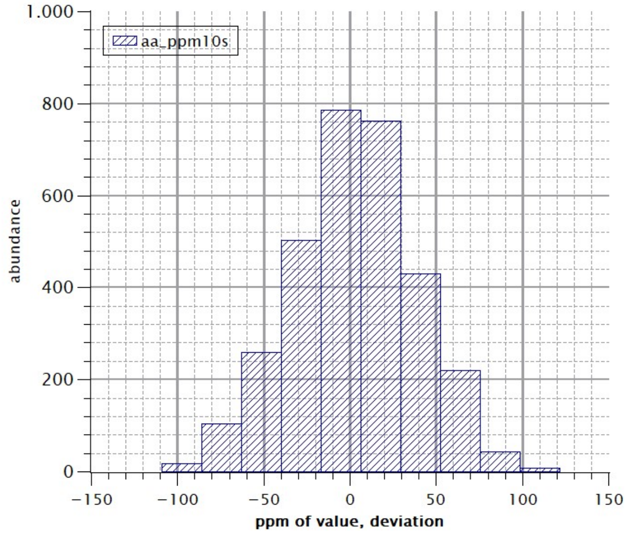

fig. 4e: **Standard version** PID, stability of output amplitude at full load (3000Vpp, 1MHz, approx. 35pF load), PID being activated. Histogram data of deviation from 1 hour average value. Integration time for output voltage measurement is 10sec.

Devices with external Resonator Box

Frequencies above approx. 8 MHz require very close proximity of the RF drive with respect to the electrode structure, to be supplied with the RF signal. To ease this problem, an external resonator case is available, which can be mounted in a convenient short distance (just few cm) to the quadrupole structure or ion trap.

Photo of external resonator box, which can be used to obtain resonance frequencies above 8MHz, e.g. 16 MHz or 20MHz. Apart from the resonator itself, the device may house high precision amplitude detection circuitry and an additional output power stage. The connection to the 19” control unit is established by a 25pole standard

Sub-D connector cable. The box can be connected to the respective quadrupole structure or ion trap vacuum flange using a very short flexible (RG174 type) cable with SMA connectors, e.g. of 10cm cable length.

Two additional options are available in this case:

Option IS-12:
This is a combined hardware/firmware option, which helps to stabilize the output amplitude on a level of approx. 12ppm rms, with respect to time intervals of seconds. A PID loop is established for this purpose and high-resolution DACs/ADCs are being employed to counteract amplitude variations with time and temperature.

Option T-PID:
This is a hardware modification, which employs a miniaturized oven, in which the amplitude sensor, which detects the output RF amplitude, is stabilized on a highly stable temperature (few milliKelvin residual variations). This helps to counteract measurement uncertainties, which arise from variations of the ambient temperature in the surrounding laboratory. Thus, the dependence on ambient temperature is reduced from approx. 10 to 20ppm/K down to approx. 3 to 5ppm/K.

Stability Example using a 20 MHz external Resonator Box

The subsequent graph depicts the measured output AC voltage (nominal value 400Vpp) of a 20MHz drive, including options IS-12 and T-PID. The graph shows the externally measured RF amplitude over a 10-hour interval. The 60 second sliding average value are also depicted (red trace), whereas the black trace has been measured taking data points each 500ms. The slight slope (from left to right) stems from a slow 5K temperature variation in the laboratory (corresponding to 5ppm/K residual temperature influence) over 10 hours.

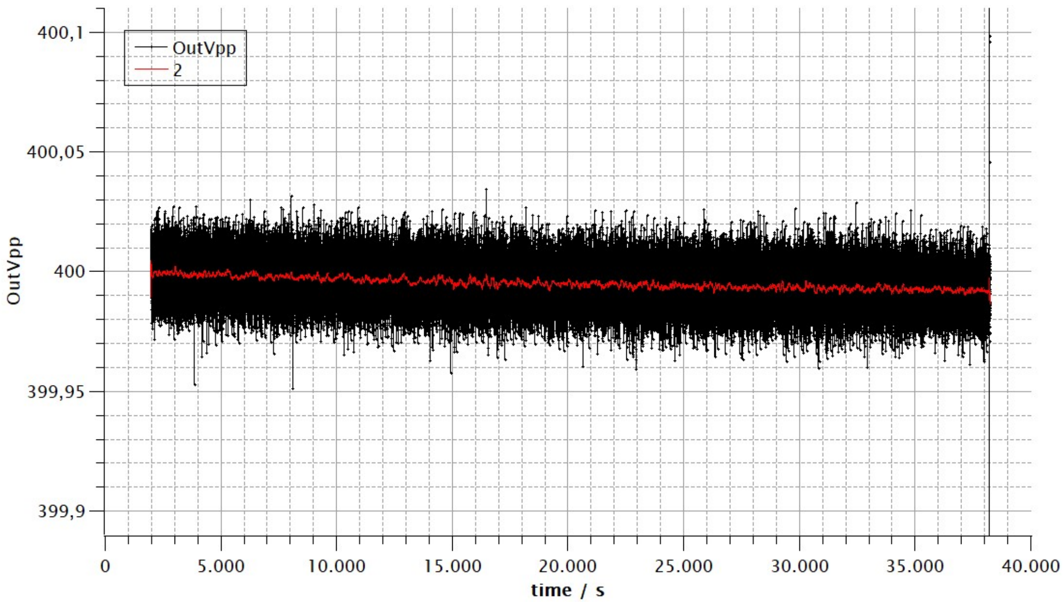

Fig. 4f: Observed output RF amplitude (Volt-peak-peak) versus time, 10 hour-interval; black trace: 500ms sampling time, red trace: 60sec average over black trace

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The observed residual amplitude fluctuations at given time intervals amount at f = 20MHz typically to:

ΔT =	500ms	35 ppm rms
	1 s	12 ppm rms
	2 s	9.9 ppm rms
	10s	5.4 ppm rms
	60s	2.9 ppm rms

These figures are being measured by taking the average value over the specified time interval and subsequently building the difference to the next interval.

Coil Exchange

This option allows for an exchange of the main resonator coil, in order to accommodate a certain range of discrete output frequencies, e.g. 1MHz to 8MHz, see also Appendix for further details.

Fan/Temperature Warning

In case there is a problem with the ventilation fans or signs of overheating inside the device, the latter is indicated by a display reading. Eventually the output is intentionally disabled for safety reasons.

Fast Turn-Off Feature (Ion Ejection)

This optional feature allows for terminating the output waveform in short time. This can be useful e.g. for releasing the stored ions out of an Ion Trap in a well-defined way. Upon activation, this circuitry swiftly damps away the energy being stored in the resonance output circuit, reducing the amplitude within approximately one or two oscillation periods close to zero.
Note that the deactivation of the output signal should not happen at a too frequent repetition rate. A rate of no more than 5 Hz (i.e. cycling the output power 5 times per second) is recommended to maintain a long lifetime of the fast-turn-off switching unit and to avoid overheating. Also note, that fastest damping is reached with highest amplitudes of the device output.
If the Fast Turn-Off feature is installed, the HF-DR device is shipped with one of two options installed: synchronized or non-synchronized mode (see also timing diagram in Appendix).
(a) In *non-synchronized* mode (which is the default version) the internal turn-off switch activates about 100ns after the corresponding signal is applied at the respective BNC input, regardless of the current phase of the output oscillation.
(b) In *synchronized* mode the internal turn-off switch is enabled (not yet triggered) after the corresponding signal is applied at the respective BNC input. The circuitry now waits for the next zero-phase transisiton of the internal RF oscillator and only then triggers the turn-off switch and damps the oscillation. This special feature allows for precise timing of ion ejection out of traps, being synchronized to the oscillator phase. This creates even better defined ejection conditions than running the system in the non-synchronized mode. Note that, depending on a possible asymmetry of the capacitive output loads, the internal oscillator

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phase does not necessarily coincide with the phase measured at the output lines, but may have a constant phase offset.

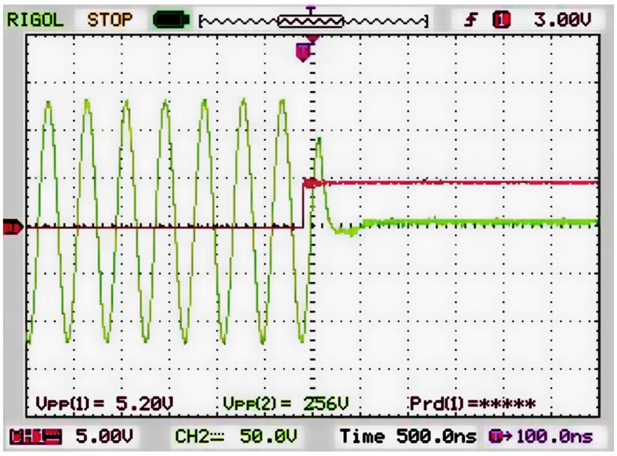

fig. 5: Experimentally measured waveform during turn-off event, device with serial number 016010.

Output Harmonics

The output waveform is essentially a sine wave with very little remains of higher harmonics. The subsequent graph depicts a typical output spectrum (measured by a Rigol DSA815 spectrum analyzer), in which the fundamental wave is visible and above the noise background of the analyzer some harmonics at multiples of the fundamental wave frequency appear.

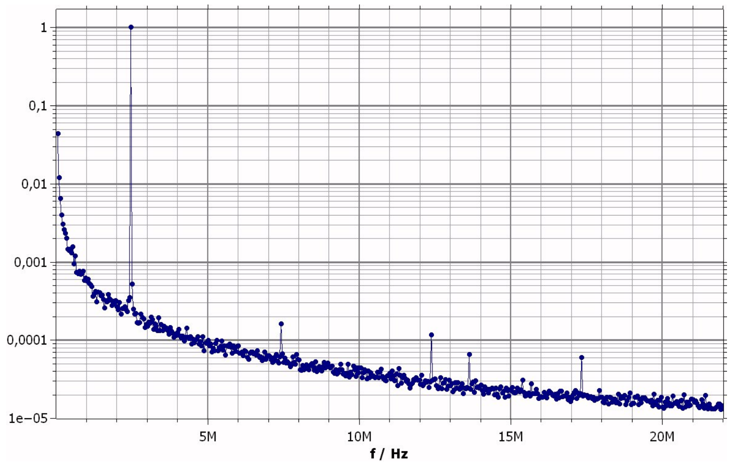

fig. 6: Experimentally measured output spectrum to illustrate the contents of higher harmonics. Fundamental wave frequency used: 2.5MHz at 500Vpp output differential amplitude (device with serial number 016010).

Remote Operation

The device can be remotely controlled by simple ASCII-commands, using the USB connection at the rear side. By pressing the 'function' button the modes are switched between local and remote. Please refer to appendix below for command syntax. In 'remote mode', manual pressing of the control keys on the front plate is disabled. The device can also be equipped with user-defined command, please contact manufacturer for this purpose.

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Specifications

Output	
Output voltage Option FL	Depending on device version: each output line max 1100Vpp (peak-peak) @ approx. 35pF load after cable; differentially 0 to 2200Vpp [1)] @ approx. 35pF load; other voltages in customized versions. External resonator box: typically 400 to 500Vpp. Note that routinely a safety limit is active, to prevent amplitudes getting too large. This feature sets the drive level to smaller values in case the max amplitude is exceeded.
Frequency **accuracy**	model depending; fixed center resonance 1.0 MHz to 8 MHz with exchange coils optionally. Versions up to 40MHz upon customization with external resonator box 50ppm standard, 1ppm optional
Output Power	typ. 10W, < 25W
Amplitude Stability PID activated, standard PID option IS-12	30ppm rms standard ΔT = 1s to 30s typ 12ppm rms optional (option IS-12) at ΔT = 1s typ 5.4ppm rms optional (option IS-12) at ΔT = 10s typ 2.9ppm rms optional (option IS-12) at ΔT = 60s (contact manufacturer for further details, see also PID section)
Tuning Capacitor Range each Channel (rear plate)	typ. 5pF to 30pF
Parasitic Harmonics Suppression	typ. 75dB (66% to 80% drive level)
Output connector type	SHV, SMA or Amphenol multipin plugs (customizable)
DC Offset (option)	max. +/-200V DC (optionally +/-500V) applied to rear side Sub-D offset input, 25pole male, or BNC input
Capacitive load capability each output	< 60pF recommended Amplitude specs are reached with not more than 35pF each output Please contact manufacturer for load on external resonator box.
Auxiliary Excitation (Option) **Input** (front plate)	0 to 10Vpp, 50Ω transfer function: approx. 1/400 of amplitude is superposed to RF amplitude

Front Plate Display Readings		
Voltage Accuracy: (voltage larger 450Vpp, or 33% of nominal max. amplitude)	typical	maximum error
Scale error	1.5%	5%
Offset error	4V	7V
Voltage Difference (floating coil option FL)		
Scale error	2%	5%
Offset error	2V	7V
Phase Accuracy (RF voltage larger 125Vpp)	typical	
error	1.5°	6°

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Environmental Conditions	
Magnetic Field	max. 5mT admissible
Storage Temperature	-55 °C to +85 °C
Operating Humidity & Temperature	noncondensing relative humidity up to 95% temperatures between +0°C to +30°C.
Dimensions	
Control Unit, 19”-fornat Size	19.00” wide x 10” deep, nominally. Front-panel mounting holes are configured for M6 rack configurations
Weight	approximately 7.2 kg
External Resonator Box (in case f > 8MHz) Size	approx. 165mm x 105mm x 88 mm
Weight	approximately 0.5 kg
Power Requirement	
AC Supply Rating	EU version AC input voltage 230V_{AC} at 50Hz, typ. 90W at max. RF amplitude US version AC input voltage 120V_{AC} at 50Hz or 60Hz, typ. 90W at max. RF amplitude. The power entry module is EMI/RFI-filtered. Fuse: medium fast blow 1.6A (EU, 230V_{AC}), 2A (US, 115V_{AC})

Note 1) : Capacitive loads must be minimized for achieving highest amplitudes. Note that dissipative effects of loads can significantly reduce maximum amplitudes; this is especially true for high output frequencies above 2MHz. At upper frequency end (towards 8MHz) highest achievable amplitude is typically 450Vpp each output, i.e. 900Vpp differentially

Software installation

USB-Driver

The device uses the USB bus for connecting to a control PC. Windows operating systems are assumed in the subsequent description. After proper cabling of the USB connection (see section before) the “Found New Hardware Wizard” under Windows should open up. Depending on the Windows version allow a few seconds to automatically identify the connected device and install drivers, or follow the described steps below. The installation procedure will install the USB CDM drivers from FTDI, which is the manufacturer of the USB bus interface circuitry.
The supplied installation CD provides suitable drivers for operation under Windows XP or higher. Latest drivers, also for different other operating systems (Linux, Mac OS, other Windows versions) can be downloaded from http://www.ftdichip.com/FTDrivers.htm.
While latest Windows versions like Win10 automatically install suitable drivers (please allow 30seconds to pass once the device has been connected), execute the following steps under Windows XP after automatic start of the “Found New Hardware Wizard”:
The following screen opens up,

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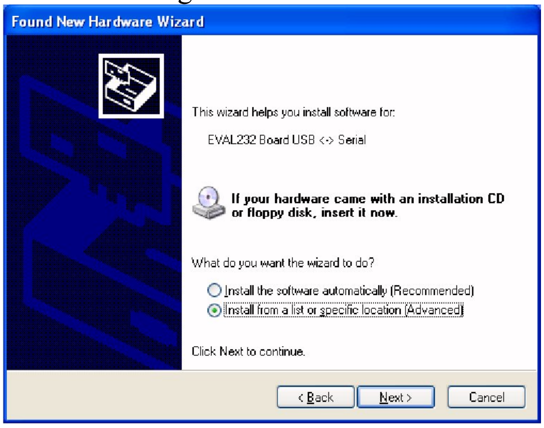
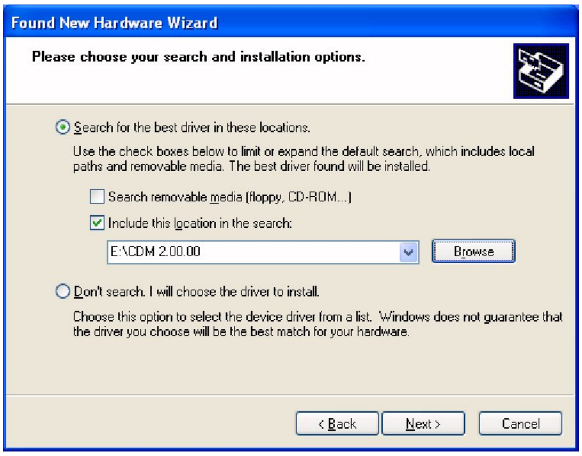
in which you activate the last button "**No, not this time**" and continue with "**Next**".

In the following window choose "Install from a list or specific location" => "**Next**"



And afterwards you choose "**Search for the best driver in these locations**" and "**Include this location in the search**". Browse now to the Installation CD and select the appropriate path with the USB drivers.



Click "**OK**" and "**Finish**" to complete the first driver installation.

After a few seconds the first window will show up again ("Found New Hardware Wizard"). This is because the driver comes in two separate parts, which both have to be installed. Go through the installation steps in the same way as before. After completion, the USB drivers are ready for use and indicate this by showing "HV Series: Device Ready" (or similar) in the lower right screen corner of your PC for a couple of seconds. Depending on operating system (e.g. Windows10^{TM}) installation of

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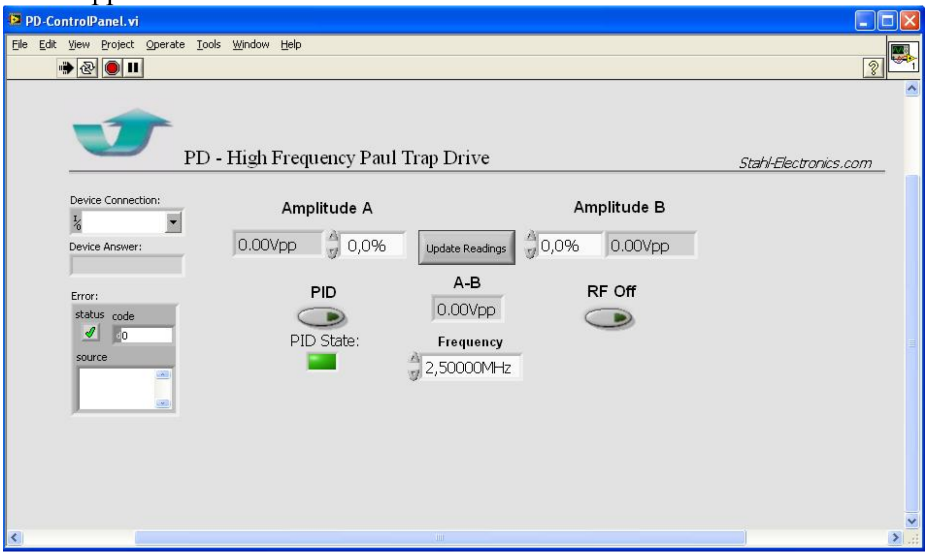
drivers may happen automatically; this will usually take 20 to 60 seconds and will be indicated by the operation system.
Remark: One known problematic point with National Instruments drivers is the fact that they tend to collide sometimes with other drivers, especially for Tektronix oscilloscopes. If in doubt the other drivers should be temporarily removed and installed again.

LabVIEW™ control program

Assuming that LabVIEW™ in Version 2013 or higher is available on the target PC, copy the path containing the LabVIEW™ source code VI's from the installation CD or USB-Stick to a place of your choice on a local drive. By double-clicking on the corresponding source file, the control panel for the device will open, which can immediately be put into operation by clicking on the start-arrow in the upper left corner.



The device parameters may be entered in the corresponding numeric fields, after choosing the established COM-connection to the device and serial number ('PD' + last three digits). Devices with option 'FL' feature only one drive level setting.

Please note, that this LabVIEW program is mainly intended for illustration purposes and in order to get started with the subject of controlling the device. In most applications the device may be controlled later by self-written code or code embedded into an experimental control framework. For this purpose, the required commands and syntax is described below. Please observe that the command set is continuously being improved and the available set of commands relates to the production date of the device (this manual version: Oct. 2021 and later)

User-Defined Remote-Control and List of Commands

Introduction

The device can be controlled using the provided LabVIEW™ cource code blocks, or by self-written program code. Standard program compilers/interpreters like C++, BASIC or Pascal/Delphi dialects may be used for this purpose and also simple command-line terminal programs (e.g. HyperTerminal™) will do. The physical line connection to the device (USB-connection 1.0 protocol, but also 2.0 compatible) needs to be established beforehand, like described in section 3.2.1. USB-

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drivers for Windows™ versions, Mac OS and Linux are provided. Please check eventually the USB-manufacturers homepage (www.ftdichip.com) for latest updates.

Note that the physical communication acts like a so-called RS232 device, communicating with standard settings (115200 Baud, 8N1 protocol, no handshake). In self-written code the 115200 Baud rate parameter needs to be set accordingly. In Windows™ operating systems the device appears on a 'COM'-port, as soon as connected to the control PC (after driver installation). The COM-Port number is assigned by Windows upon connecting the device by USB cable and may change from time to time. The COM-Port settings may be checked by the user inside the Windows™ system control panel.

Command List

Inside this table the abbreviation "DDDDD" represents the name of the device including its serial number, e.g. "PD001" means a device with serial number "001". All commands must be terminated with an CR ('carriage-return') symbol "↵" (13 in ASCII code). First, after establishing the USB link to the HV device and turning it on, the IDN identifier should be sent in order to retrieve the serial number, since this serial number will be used to address the device correctly. See also examples and more details after the table.

Command Function	**ASCII Strings** sent to device or received + CR ('carriage-return') at string ends	**Observations and comments**
Identify device	sent IDN received DDDDD … … …	The device replies with its name, serial number (DDDDD) and further information. See also examples below this table.
Set Frequency	sent DDDDD F XXXXXXXX received Frequency Set	The frequency of the output signal is set. XXXXXXXX is a decimal number between 00000000 and 10000000 which represents the the Frequency in Hz. Device must be in Remote Mode!
Set Amplitude	sent DDDDD X <float> received <float>	The amplitude of Channel X('A' or 'B') is set. <float> is a decimal number between 0 and 100 with up to 5 decimal places which represents the percentage of the maximum voltage of the internal DAC for the selected Channel. For Devices with a single drive level Channel = Channel B. Note that the number decimals depends on the device version and selected PID accuracy level. Device must be in Remote Mode !
Set Max Amplitude	sent DDDDD MAX <float> received <float>	The maximum amplitude is set, which limits the output amplitude. Upon exceeding, the drive level is reduced by 1/3. <float> is a decimal number which represents the maximum output amplitude. Caution do not change this value frequently, the internal non volatile memory (EEPROM) has a limited number of write cycles (several 10000).
Read Max Amplitude	sent DDDDD R MAX received <float>	Read back the current amplitude limit. <float> is a decimal number which represents the maximum output amplitude.
Activate/ deactivate software PID loop	sent DDDDD PID OFF or DDDDD PID OFF received PID Started or PID Stopped	This command activates deactivate the PID loop to hold the output amplitude constant

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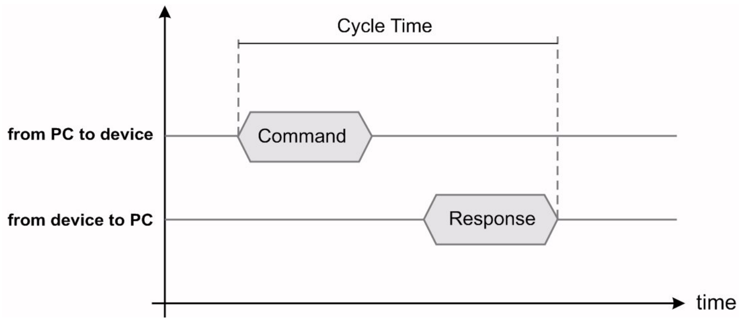
RF ON/ OFF	sent DDDDD ENABLE or DDDDD DISABLE received RF Enabled or RF Disabled	ENABLE enables the RF output and DISABLE disables it. Caution: Switching from remote in local mode automatically enables the RF output, if not disabled by the front panel switch or BNC input. Device must be in Remote Mode.
Read Amplitude	sent DDDDD R X received X.XX or XX.XX or XXX.XX	Reads the amplitude of channel A, B or the differential amplitude (X = 'A','B' or 'D'). Caution: the return string has no fixed length. For example, an amplitude of 86.29Vpp will return 4 digits and an amplitude of 239.04Vpp will return 5 digits. Device can be in any mode.
Read PID state	sent DDDDD R PID received PID OFF or PID OK or PID OUT OF RANGE	Reads the state of the PID loop. Device can be in any mode.
Read back Frequency	sent DDDDD F? received XXXXXXXX	Reads back the frequency in Hz with leading zeros (8 digits).
Read back set Amplitude	sent DDDDD X? received X.XXXX or XX.XXXX or XXX.XXXX	Reads back the currently set Amplitude of A or B (X=’A’ or X=’B’) in percent of the maximum Voltage of the internal DAC. Caution: the return string has no fixed length.
Device in Local Mode	sent DDDDD L? received 0 or 1	Checks if device is in Local Mode. 0: Remote Control 1: Local Mode

Communication Speed

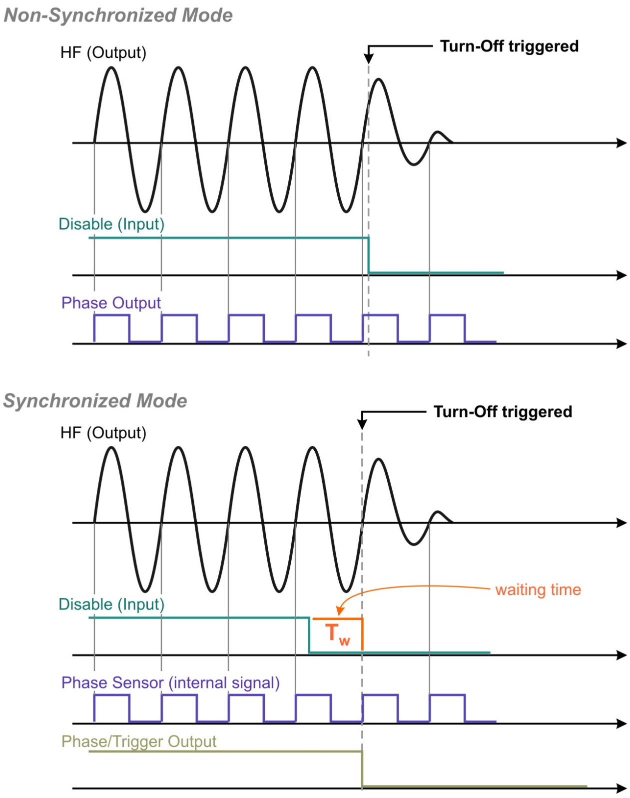
The device has a nominal USB-transmission speed of 115200 Baud (115200 Raw-Bits per second). Note that this speed grade corresponds to the 'Fast-Mode' regarding the HV- or BS-Series devices from Stahl-Electronics. However, the cycle time as illustrated below can be up to 25ms. In self-written program allow sufficient time to pass to avoid data collsision and ‘jamming’ of the serial connection, e.g. by waiting for each device answer before sending the next command.



Fast Turn-Off Modes, Timing

If the Fast Turn-Off feature is installed, the device can extenuate the output oscillation within short time. The HF-DR device is shipped with one of two hardware options installed: synchronized or non-synchronized mode. A special version is also available, which allows for selecting non-synchronized/synchronized mode by means of a switch on the front plate. Otherwise, the non-synchronized one is the default version if no other version is chosen at time of ordering the device.

(a) In ***non-synchronized*** mode the internal turn-off switch triggers shortly after the corresponding signal is applied at the BNC disable input (low level → turn amplitude off), regardless of the current phase of the output oscillation. This phase of the output oscillation can be monitored at the 'Phase Output' terminal on the front plate.
(b) In ***synchronized*** mode the internal turn-off switch is enabled (not yet triggered) after the corresponding signal (low level) at the BNC input and finally triggers after a waiting time T_w at the next occuring zero-phase transition.



In this case the BNC-'Phase Output' shows (with a high-low transition) the time, when the turn-off switch is finally triggered.

Optionally, it is possible to equip the device with a switch to select either synchronized or non- synchronized operation.

Timing schemes, depicting non-synchronized and synchronized fast turn-off features

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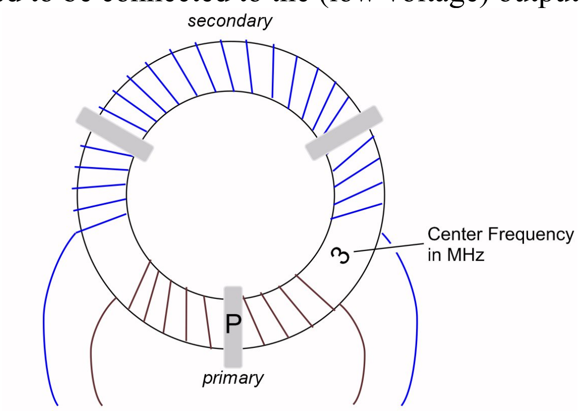
Exchangeable Coils

This device can be ordered with an exchangeable coil set to accommodate a certain range of target frequencies. The subsequent diagram shows the general structure of the resonance coils, consisting of a toroidal core and copper wire winding. In case of option 'FL' they consist of a secondary winding, in which the high output voltage is generated and a primary winding, which is supposed to be connected to the (low voltage) output driver.



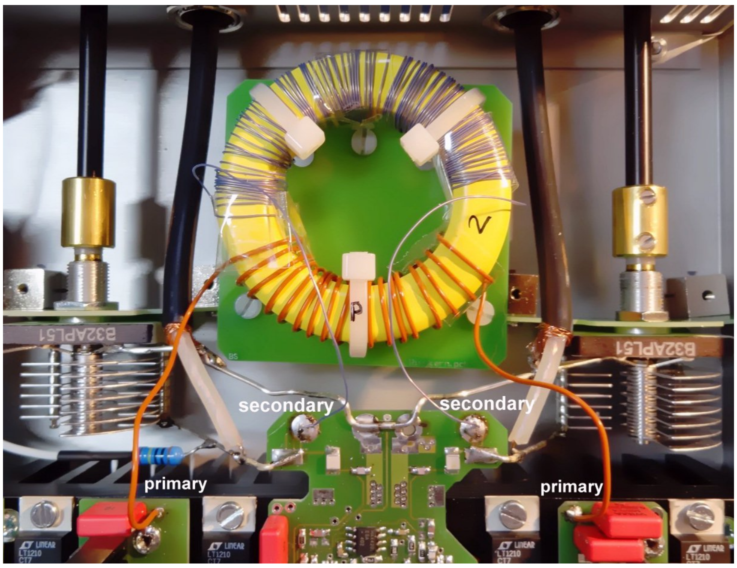
The coils may be marked with a 'P' on the primary side, facing towards the front side of the device. On top, the nominal center frequency is marked. Please note carefully, which connection wire is which one (primary / secondary) when connecting to the corresponding solder pads. **Beware to never mix them up**.

Mounting / Dismounting the resonance coil
(Attention: Device must be completely turned off during this procedure!)

The exchangeable coil option comes in two possible versions:

a) Soldered version
b) Fast Mount version

a) Soldered Version



Carefully locate the 4 solder pads, to which the 4 coil wires are connected

In order to dismount a coil, remove the 230V mains plug, open the lid of the device (6 x M3 screws), locate the coil and de-solder carefully the 4 connection wires with a normal electronic-works solder iron. **Attention:** be careful not to touch the red capacitors with the soldering iron tip, since they would melt and be destroyed or damaged. Subsequently unscrew the 3 Nylon M3 screws and carefully remove the coil.

Mounting a new resonance coil

For mounting a new coil, simply reverse the order of steps, described above: mount the new coil and fix the latter carefully with 3 x M3 Nylon screws (no metal screws), cable tie 'P' facing to the front of the device. Subsequently connect the 4 loose ends to the corresponding solder pads on the driver printboard. Do this carefully (using normal Tin-Lead solder), avoid touching the red capacitors and do not stick the wire ends too deep into the solder pads: in case placed too deep they might create a short cut with the underlying black cooling radiator. Make sure not to mix up primary (low voltage) and secondary (high voltage) windings!
After sucessful mounting, close the lid, plug the 230V connector again, turn on the device and gradually increase the drive level (to e.g. 30%) in order to check correct functionality and resonance of the new coil. Note that the resonance will generally shift to lower frequencies (typically 10% to 20%), when connected to a trap or quadrupole structure setup.

b) Fast Mount version (plug/socket)

This version allows for faster and easier exchange of resonance coils. As depicted in the subsequent photos, the coils are delivered with gold plated high-performance pin-plugs, which fit into mating sockets inside the device. To exchange a coil, unmount the M4 Nylon screw, which holds the coil in place, exchange to new coil (apply only very *carefully* force in order not to damage the gold-plated plugs/sockets and pull/push only **straight**, never tilted) and fasten again the M4 screw.

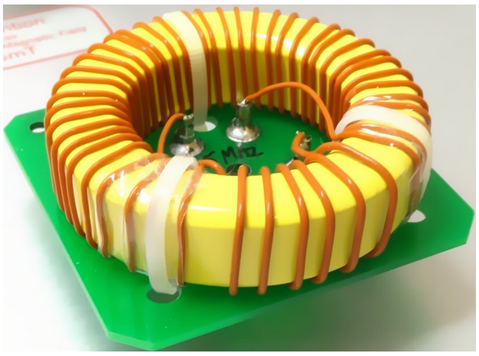


Table of optional coil set:

Center frequency (nominal)	Coil inductance (secondary winding)	**Maximum** operating voltage (Option FL), if permanently operated, differentially between the two outputs
1 MHz	440 µH	2000 Vpp
1.5 MHz	195 µH	2400 Vpp
2 MHz	84 µH	2400 Vpp
3 MHz	53.5 µH	2400 Vpp
4 MHz	25.3µH	2200 Vpp
5 MHz	17.1µH	2000 Vpp
8 MHz	6.6µH	900 Vpp

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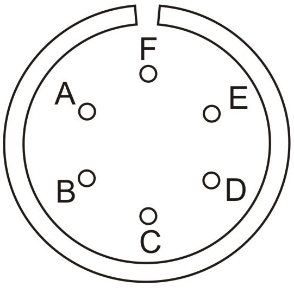
Note, that higher resonator frequencies, like 16, 20 or 40 MHz are implemented in external resonator casings, not internal ones as described above. Please contact manufacturer in this case for further details. Note also that the standard exchangeable coil set refers to output voltages of max. 2400Vpp. For larger values please contact manufacturer.

Appendix

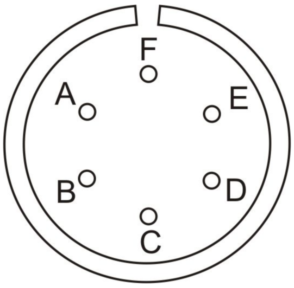
Optional Amphenol Multipin Plugs

Pin assignment device with Amphenol Multipin Plugs
(e.g. serial number 016010)
Output A:



A: 1
B: 2
C: 3 + Excitation line
D: 4
E: 5
F: 6

Output B:



A: 7
B: 8
C: 9
D: 10
E: 11
F: 12

Connection cable to Bias-Supply (ser. nr. 0170092), SubD- 25pole:
Pin numbers correspond to DC channel numbers 1 to 12; GND is provided by the cable shield mesh.

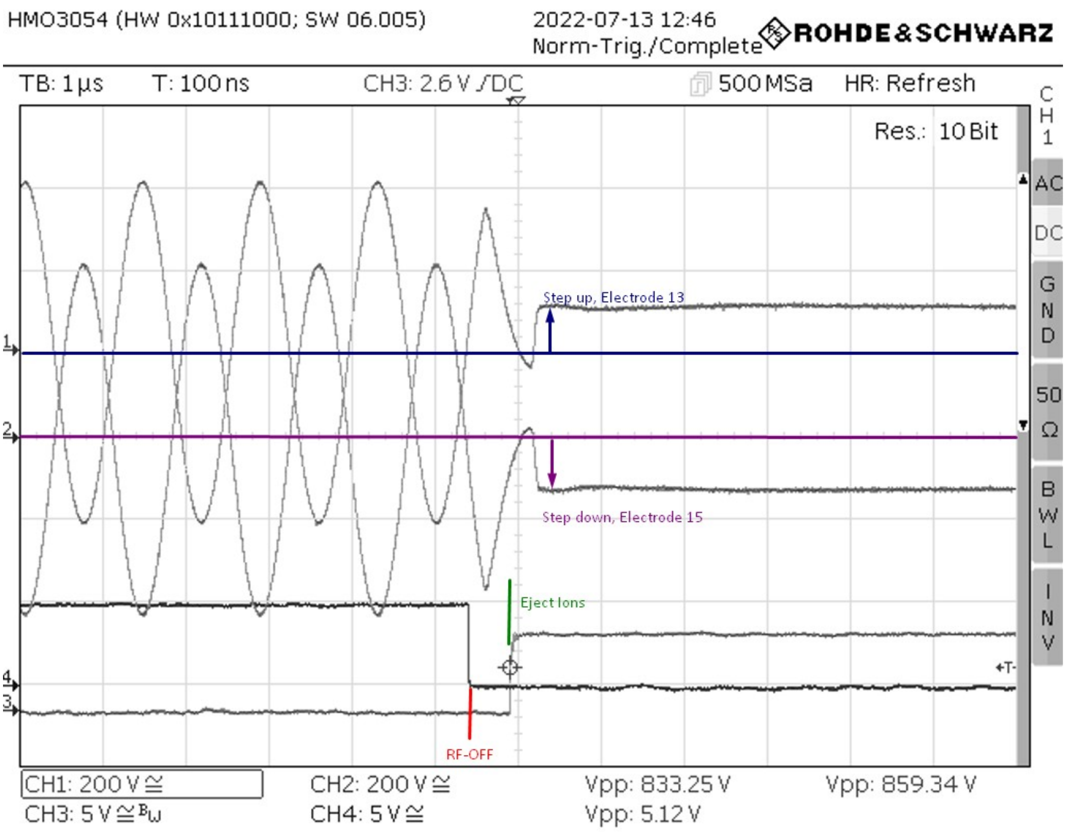
Option Multipole AC/DC Combiner for Ion Quadrupoles

This option allows to superpose the RF trapping voltage with DC voltage for (static) ion trapping, and also allows for pulsing of elements. Its output connector (e.g. Vacom PLUG-MPC2-32-P-CLG) is meant to connect to a mating vacuum feedthrough flange connector.
The photo below depicts such a unit. One can see the round-shaped connector to a vacuum flange and two more cables entering at the left side, the black carries the RF, the grey the DC voltages. The DC voltages are fed through a standard 25-pole SubD (male) plug.

The pin assignment is (unless customized)

SubD	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
Flange	A	B	C	D	E	F	G	H	J	K	L	M	N	P	R

Optionally, also pulses may be added, to ease ejection of ions out of a linear quadrupole structure. In this case, the voltages on the output pins are a linear superposition of 3 parts, the corresponding DC voltage, AC (RF) voltage and a pulse voltage. The pulses are applied to additional BNC input. Note *either* positive *or* negative pulses must be applied, depending on the chosen polarity.
The subsequent picture shows the screenshot of voltages at ion ejection event. One can see the RF on two electrodes (about 850Vpp each), their decrease towards zero after an RF-off-trigger (this assume that the FSO option is installed, see page 13), and two pulses being added to the depicted voltages (+100V on the upper track, -100V on the lower track).



Screenshot of voltages at ion ejection event. Upper voltage traces at 200V/div, horizontally 1µs/ div.

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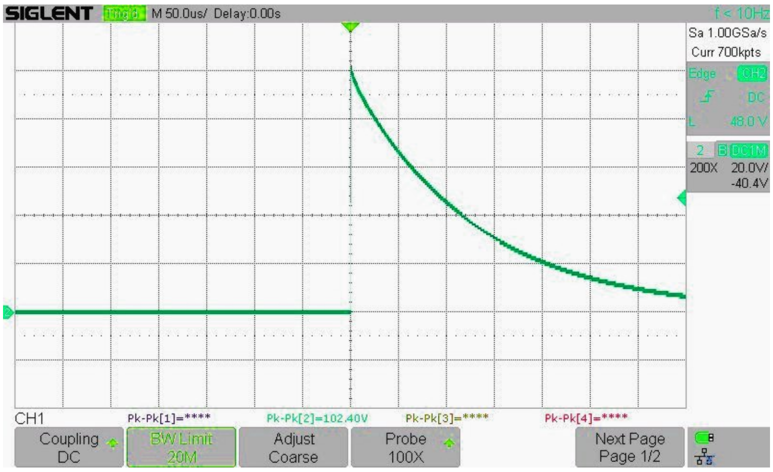
Please note that pulses must only be added if the RF has been **turned off**, at least 500ns earlier, to avoid overheating of the pulse circuitry.

After application of pulses, they *decay* again, on a longer time scale, as shown in the screenshot below (50µs/div in contrast to 1µ/div as above). This means that after about 1milliseconds, the circuitry has returned to the initial state and is ready for the next pulse.

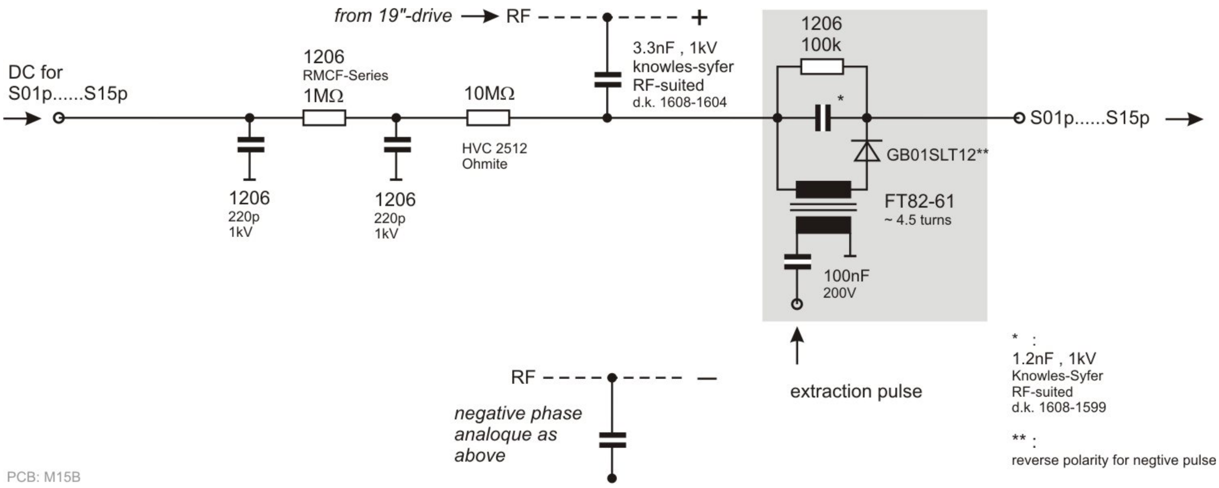


Decay of added pulses on a time scale of hundreds of Microseconds.

<u>Maximum ratings of AC/DC Combiner:</u>

DC voltages versus GND	max. +/-400V
DC voltages Pin versus any other Pin	max. +/-300V
AC voltage (RF)	max. 3MHz, max. 450Vpk (=900Vpp)
Pulses (option)	max either +200V , or -200V, depending on chosen polarity

Circuitry of AC/DC Combiner



Circuitry of AC/DC Combiner. They grey shaded area applies only if the pulsing option is implemented. The diode orientation relates to positive pulses, for negative pulses the direction is reversed

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DECLARATION OF CONFORMITY

Manufacturer's Name: **Dr. Stefan Stahl**
- Electronics for Science and Research -

Manufacturer's Address: **Kellerweg 23**
67582 Mettenheim
Germany.

Declares, that the product

Product Name: **HF-Drive (Paul Traps)**
Model Number: **HF-DR**

Product Options: **This declaration covers all options of the above product(s)**

Conforms with the following European Directives:

The product herewith complies with the requirements of the:

1. Low Voltage Directive 73/73EEC;

2. EMC Directive 89/336/EEC (including 93/68/EEC) and carries the CE Marking accordingly

Date Of Issue

21. Jan 2017 **General Director**

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