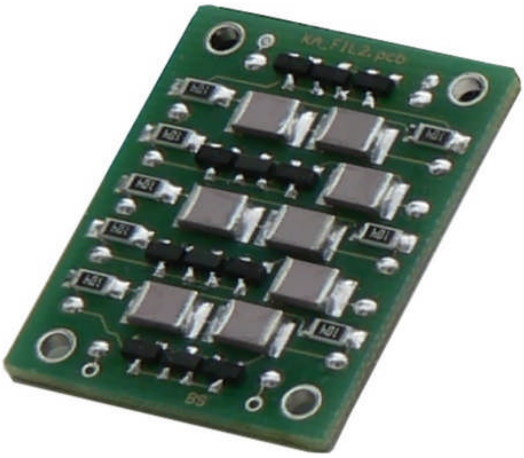
Cryogenic Low Pass Filter Unit

Type KA-Fil 2a



- Datasheet -

Version 1.1

Features:

- **5 Independent Low Pass Filters**
- **Operating Range 300K to 4.2K**
- **Overriding Diodes allow Bypassing and Pulsing**
- **Small Size**

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Introduction and Functional Description

The filter unit KA-Fil 2 contains 5 independent low pass filters for room temperature and cryogenic use. The main application is the provision of low noise environments at cryogenic Penning Traps, allowing to achieve low ion temperature and small ion energy respectively. After connecting the filter unit to appropriate trap electrodes, the filter unit keeps away unwanted electrical noise to a certain degree and prevents heating of the stored particles in a noisy electrical environment. It is possible and also recommended to place the filter unit close to the ion trap directly inside vacuum.

4 of the 5 channels on the KA-Fil 2 can be overridden by an internal arrangement of special Schottky diodes, which are able to operate in cryogenic environments. This allows for intentional excitation of ion motions, like rotating wall compression, magnetron axialization or excitation of cyclotron or axial motion. In order to override the filter function, a sufficiently high excitation amplitude in the order of $3V_{pp}$ is required at the filter input. The output override signal amplitude is in a wide range independent from the signal frequency (see fig. 9). The diodes threshold voltage is selected such, that most of noisy signals, being small in amplitude ($<1V_{pp}$), will be blocked, but intentional excitation signals can pass. The graphs in figures 7 and 8 illustrate this non-linear threshold behaviour.

Additionally, large signal pulses can be applied, which bypass the filter elements as well. This feature can be used for pulsing of the trap electrodes for ion capture or ejection purposes. For details see page 4, 5 and figure 10.

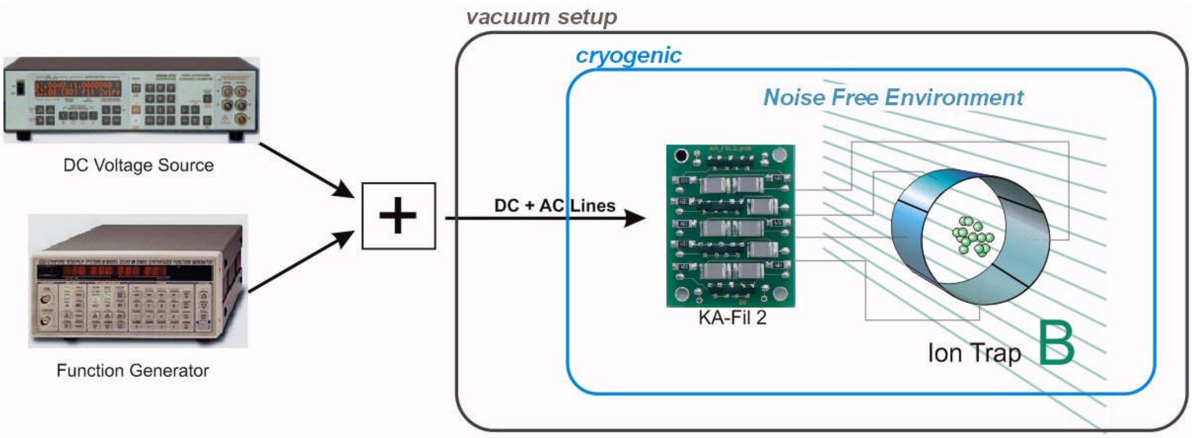


Fig. 1: Typical application: Provision of noise-free environments in cryogenic Penning Traps

Internal Structure

The following diagram illustrates the internal structure of the devices. The independent 5 filter channels are composed of 3 different types of filters. Denominated as “type 1” is a single stage RC low pass with diode bypass, denominated as “type 2” is a double stage RC low pass with diode bypass, and “type 3” is a double stage RC low pass, without diode bypass. All filters share the same ground which is also connected to the rear plane of the filter board and metal plating of the four mounting holes.

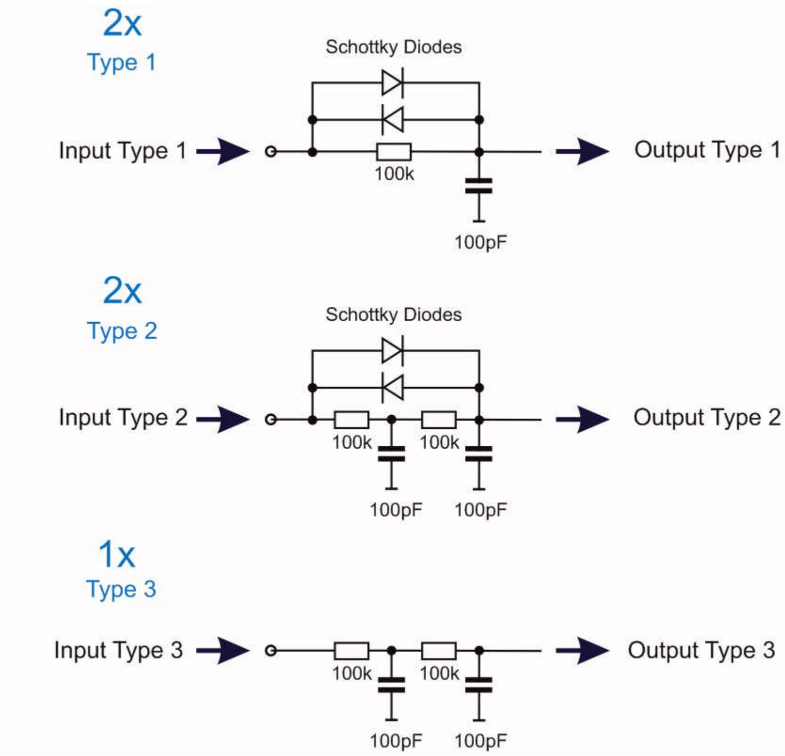


Fig. 2: Illustration of internal structure. The filter unit consists of 5 independent filters, being grouped into three different types.

Solder Pad Layout

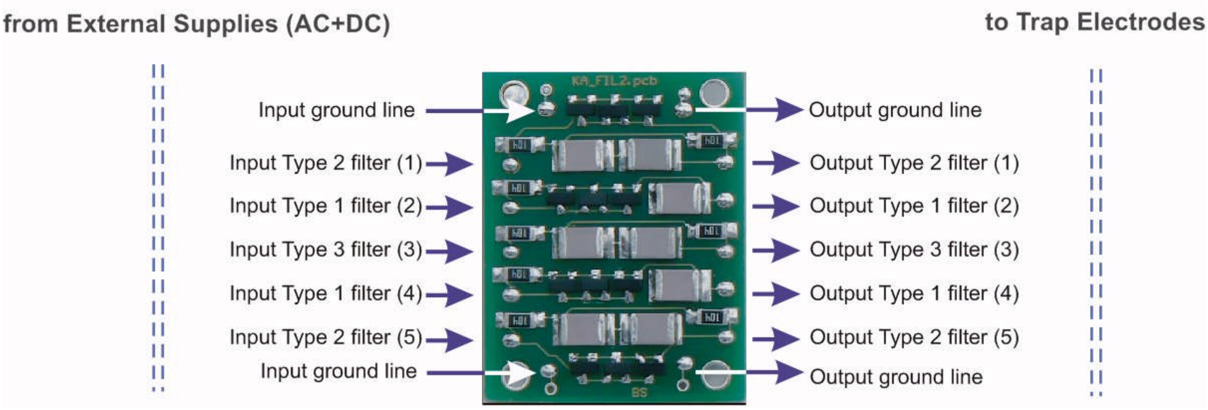


Fig. 3: Solder Pad Layout. Connect the supply lines (AC+DC) to the pads at left side (inputs of filters (1) to (5)) of the filter board and the outputs at right side to the trap electrodes.

Connecting the KA-Fil 2 Unit

Normal soft solder procedure is recommended to connect the inputs, outputs and GND. A suitable solder is the standard lead-tin alloy Sn60Pb38Cu2, which maintains some degree of flexibility at low temperatures without getting brittle. At time of shipment all solder pads contain intentionally remains of solder flux, in order to ease the solder process. The solder pads can be connected to copper wire, CuNi alloys (e.g. Constantan), brass wire or silver or gold plated wires. Stainless steel is not recommended due to its poorer joint reliability, unless special solder fluxes are used.
While performing the solder process by normal hand soldering, a heating time of minimum 4 sec. is recommended in order to allow the organic flux completely to evaporate, minimizing subsequent outgassing loads inside a vacuum setup.
It is recommended to place the Ka-Fil 2 unit *closely* to trap electrodes, in order to avoid pickup of unwanted noise on the remaining wire distance (between trap and KA-Fil 2).
The ground connections are important to provide proper functionality. Both input and output ground lines should be connected to the trap ground and the common ground of the vacuum setup respectively.

In case the input ground is NOT properly connected to the vacuum setup ground or shielding ground, the filters will NOT establish well their filtering effect. Keeping the ground line close to the signal lines is recommended as well as providing it as massive (thick copper wire) as possible without sacrificing thermal loads too much, in case the setup is cryogenic. In case that thermal load is critical in the setup, it is also possible to use “RF strand” line, consisting of a bunch of multiple (e.g. 30x) singly isolated 50µm copper wires.

Applying the signals for trap electrodes

DC voltages will pass through the filter elements and pass to the trapping electrodes, being filtered in order to abandon unwanted noisy signals. The corner frequencies, above which the filters are active, are in the kHz-region and depend on filter type and operating temperature (see subsequent figures).
Voltage rating of the DC voltages is +/- 800V maximum.
AC voltages will be *suppressed* by the filters by roughly a factor of 25 (type 1 and 2 filter) between frequencies of 100kHz to 30MHz. If large AC signals are applied, the bypassing diodes will become active, temporarily cancelling the filter elements and allowing the signals to pass. This non-linear functionality between input and output voltages is illustrated and quantified in figures 7 & 8.
Pulses of both polarities can be applied for switching purposes, e.g. to drive a capturing electrode or to switch electrodes for ion ejection purposes. In this case, a maximum pulse current of no more than $1.4A_{pk}$ must be applied, especially when the unit KA-Fil 2 is used in vacuum and under cryogenic conditions. For instance, if a pulse height of $140V_{pk}$ is applied, an additional resistor of 100Ω must be placed in series in order to avoid overloading of the Schottky diodes. One must keep in mind that this protection resistor in conjunction with the filter capacitors (100pF) and parasitic trap capacitance (e.g. 25pF) will form a parasitic low pass. Its time constant, taking into account the numbers mentioned

above as an example, will be around 12.5ns. If this may be of relevance or not, will depend on the type and speed or particles used in the setup. Worst case are very fast ions or very light particles like electrons.

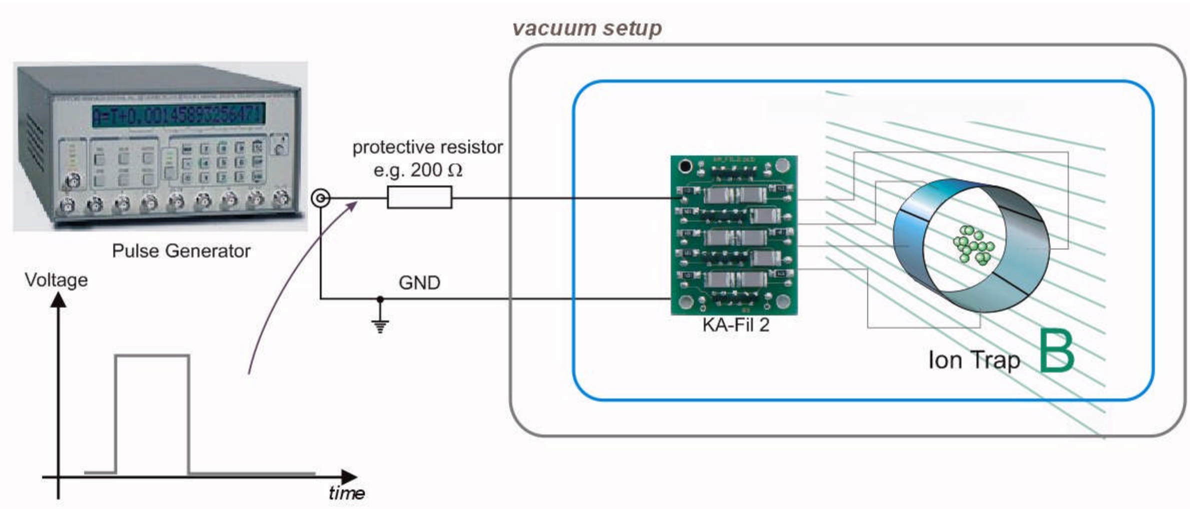


Fig. 4: Voltage Pulses, higher than $3V_{pk}$ will pass through the filters (type 1 and 2) essentially without attenuation, allowing pulsing of electrodes in favour of ion capture and ion extraction (see also fig. 10). In case voltage steps bigger $10V_{pk}$ are applied, one additional protective resistor is required in order to limit the maximum peak-current values. The resistor should be of non-inductive style and scales essentially proportional to the voltage step size. E.g. 140V step => 100 Ω, 280V step => 200Ω. See also text above and table 1 below.

Absolute Maximum Ratings

Note: Stresses above these ratings may cause permanent damage or degradation of device performance. Exposure to absolute maximum conditions for extended periods of time may degrade device reliability.

Quantity	Limits		Remarks
	min.	max.	
DC Voltage vs. GND		± 800V	T <= 300K
DC Voltage between adjacent channels		± 600V	T <= 300K
AC Voltage, sine wave, permanently (type 1 and 2 filters)		$10V_{pp}$	@ maximum 20MHz, capacitive load 100pF on filter output
AC Current, sine wave, permanently (type 1 and 2 filters)		80 mA_{rms}	
Pulsed Currents (type 1 and 2 filters)		1.4 A_{pk}	at repetition rate of no more than 20Hz, see also fig. 4
Storage Temperature	3.5K	125°C	Baking is possible up to 125°C, max. for 48 hours
Storage Humidity		65% @ 40°C	

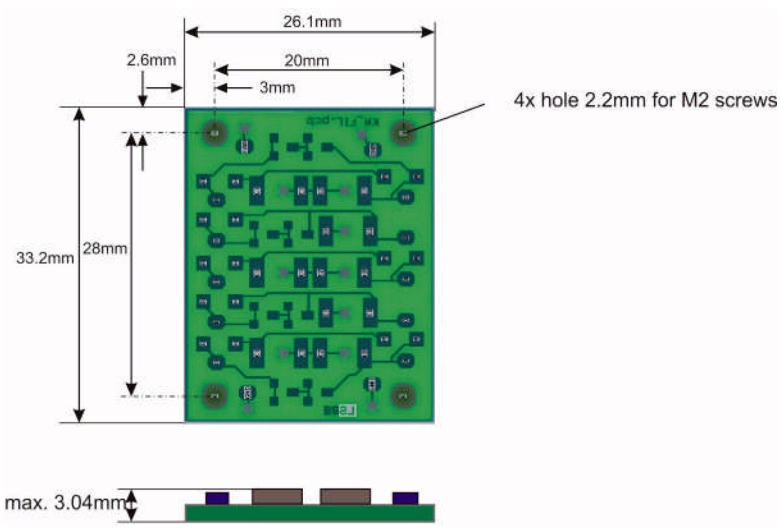
Table 1: Absolute Maximum Ratings

Characteristics and Operating Parameters

Parameter	typical Value		Remarks/Conditions
Corner Frequency (-3dB) of filters 300K, type 1 300K, type 2 & 3 4.2K, type 1 4.2K, type 2 4.2K, type 3	12.5 kHz 6.1 kHz 6.9 kHz 4.2 kHz 2.5 kHz		capacitive load 20pFat outputs
Static Series Resistance between input and output filter type1 type 2 & 3	T = 300K 100 kΩ 200 kΩ	T = 4.2K 235 kΩ 460 kΩ	no AC components applied, or smaller 300mVpp
Dynamic Series Resistance between input and output filter type1 & 2	7.4Ω	20Ω	AC signal components > 3Vpp applied, signal current $30mA_{rms}$, signal frequencies < 50MHz
Isolation Resistance between input or outputs to GND	>100MΩ		@ T = 300K ... 4.2K applied voltage < $+/-250V_{DC}$
Noise Suppression filter type 1 @ 4.2K filter type 2, 3 @ 4.2K	22dB 23dB		@ f = 100kHz … 30MHz
Operating Temperature	T = 4.2K...323K = -269°C...50°C		
Magnetic Properties	Device consists mostly of non-magnetic materials. spurious amounts of ferromagnetic substances < 5 x 10^{-3}gr. possible		It is recommended to locate the device > 5cm away from precision ion traps/FT-ICR cells in order to avoid magnetic disturbance
Geometrical Size	33.1mm x 26.1mm x 3.0mm		
Outgassing	(to be determined)		
Substrate Material	glass-fiber reinforced epoxy resin, copper layers (35µm)		
Weight	~ 5 gr.		

Table 2: Characteristics and Operating Parameters

Geometrical Outline



Typical Characteristics

The data in the following graphs were obtained using the setup arrangement sketched below. A signal or pulse generator delivers signals, which were sent through a 2.4m long 75 Ω cryogenic coaxial line to the Ka-Fil 2 unit, being dipped into liquid Helium in a dewar can. After passing through the respective filter channels the signal is fed back through a second 75 Ω cable to an oscilloscope for analysis. In order to ensure comparability, all AC measurements at T = 300K are performed using the same geometrical arrangement, but without the Helium can. The parasitic capacitance of the coaxial line was measured to 101pF/m ± 5%.
Since the large size of the setup imposes influence on the measured transfer/filter functions, the high frequency behaviour of the filter board itself (without extensive cables) was additionally measured at 300K using a small shielded metal box (see figures 6c, 6d).

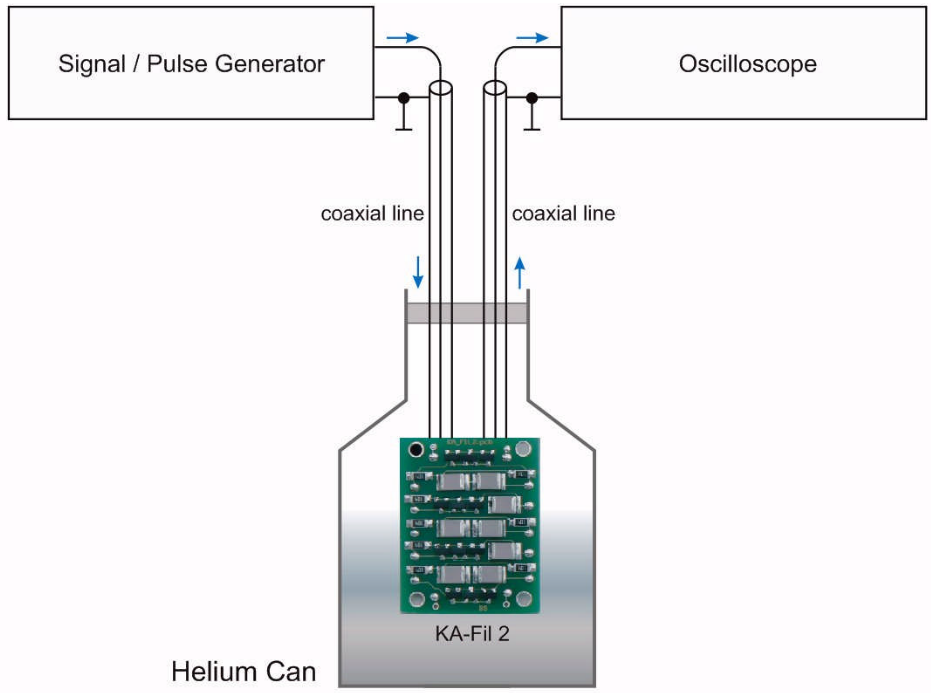


Figure 5a: Sketch of setup for the AC measurements, data shown below in subsequent graphs.

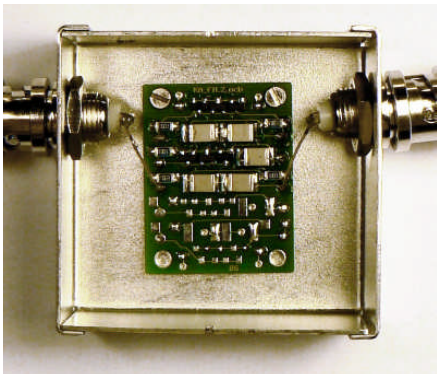


Figure 5b: Data in figures 6c, 6d were taken using a shielded metal box to exclude the influence of cryogenic cabling

Characteristic Data

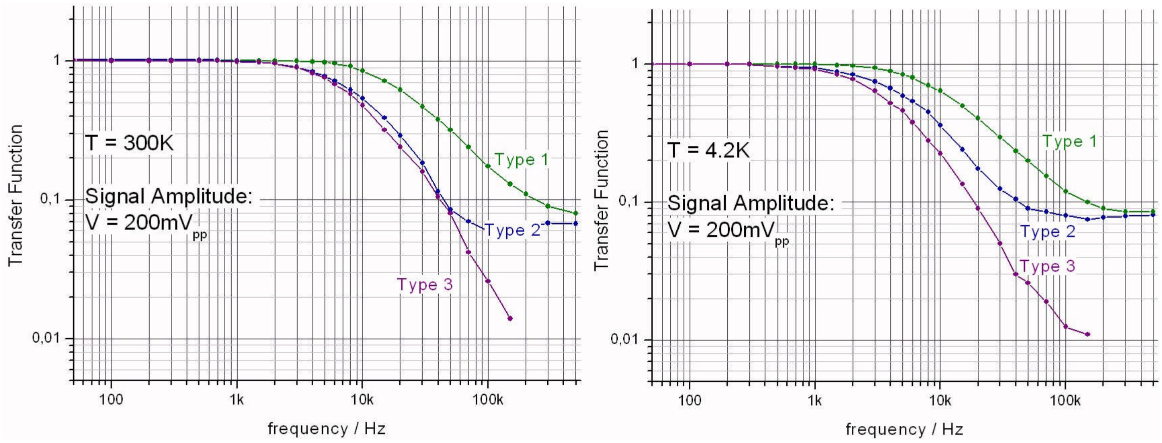


Figure 6a, b: Amplitude transfer function of filters type 1 and 2 at 300K and 4.2K

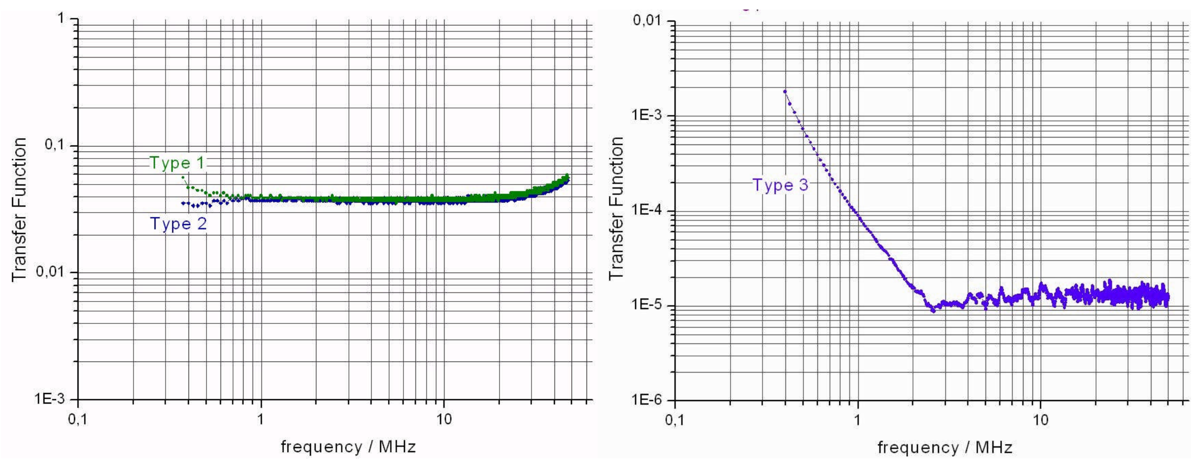


Figure 6c, d: Amplitude transfer function of filters type 1, 2 and 3, determined by network analyser at 300K. The filter board is mounted in a shielded metal box to exclude the influence of cryogenic cabling (see figure 5b). Output signals are measured with a high impedance (1MΩ + 12pF) probe.

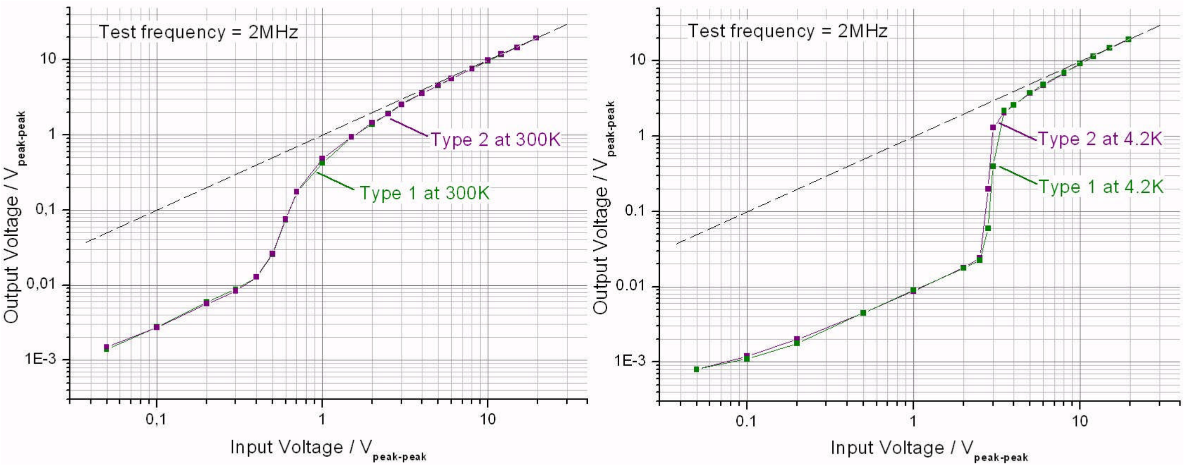


Figure 7a, b: Output voltage (Volt peak-to-peak) vs. input voltage (sine wave) at T = 300K and T = 4.2K, at test frequency = 2MHz. Setup according to figure 5a.

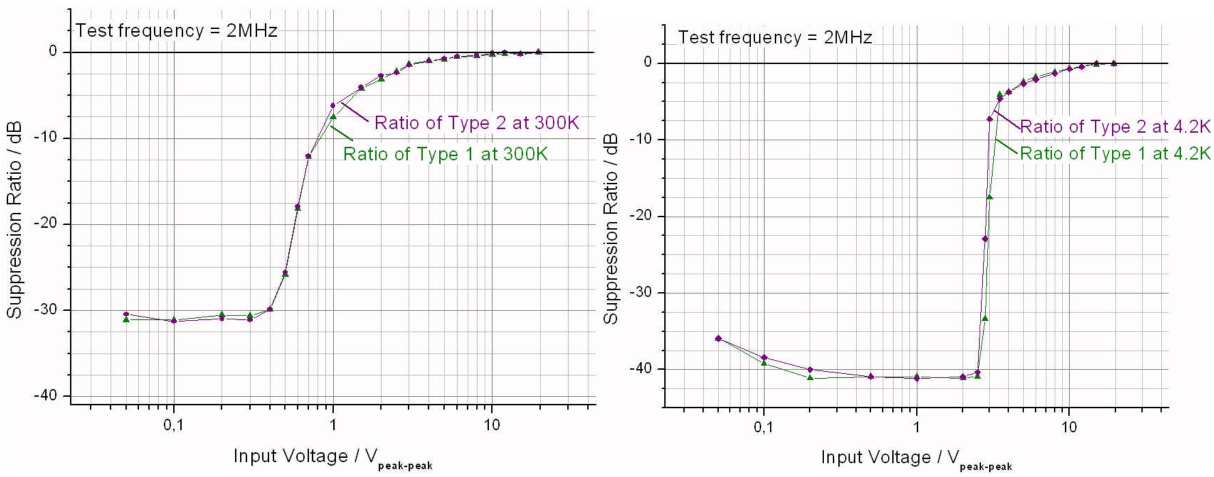


Figure 8a, b: Suppression ratio and bypass effect of input signals (sine wave) at various amplitudes (same data set as in fig. 7), expressed in dB.

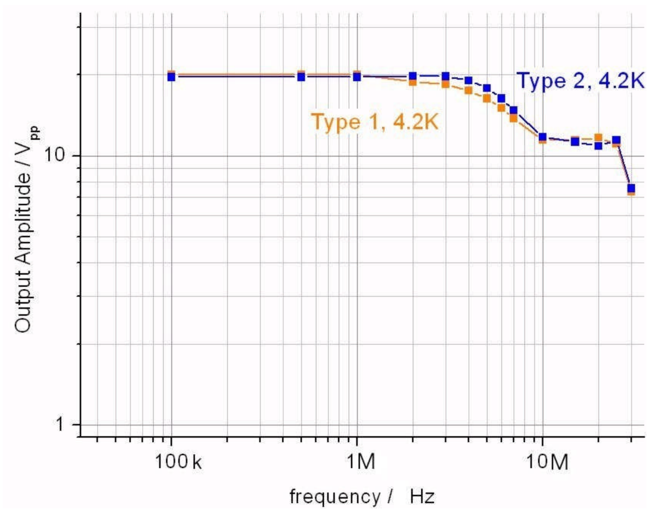


Figure 9: Large amplitude behaviour for f = 100kHz to 30 MHz at T = 4.2K ambient temperature. Input amplitude is fixed to $20V_{pp}$, 50 Ohms source impedance. Setup according to figure 5a.

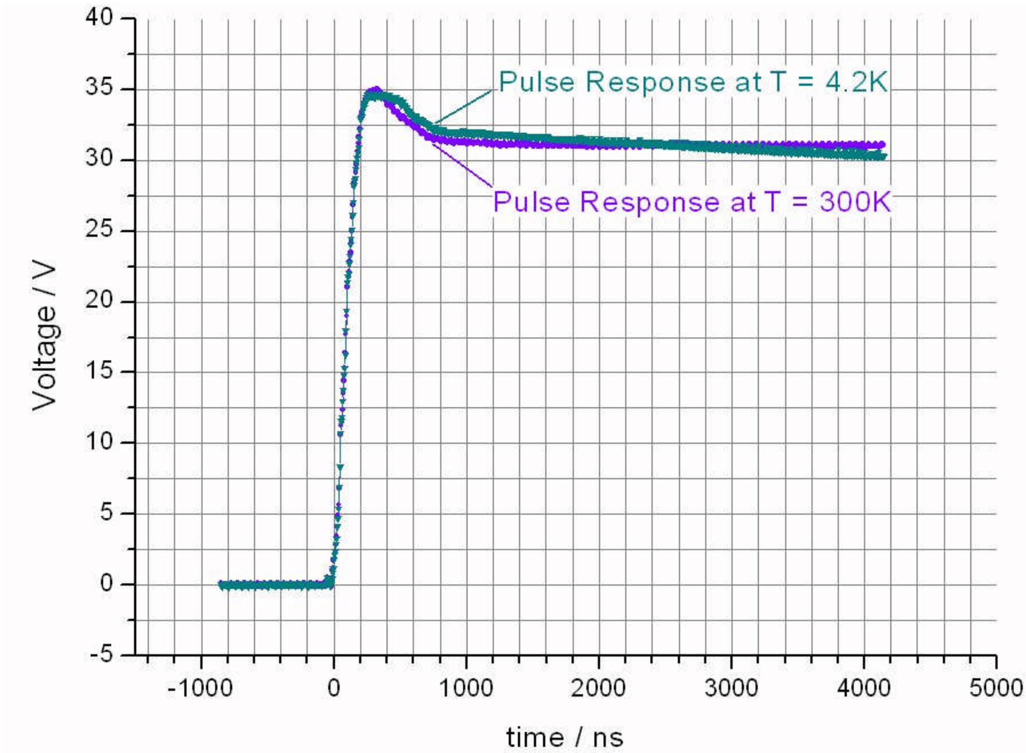


Figure 10: Pulse response at filter output, using a +33V signal step at input, type 1 or 2 filter. The pulse source (Berkeley Nucleonics type BNC555 with 20.0 Ω series resistor) features 75ns rise time to achieve 85% of amplitude at the filter input. Setup including cryogenic cabling, according to figure 5a. Capacitive load on the filter output is dominated by the cable capacitance of about 230 pF.

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