Using the RPR-4000 in amplifier mode

AN-12

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Introduction

The RPR-4000 includes an internal signal synthesizer that is capable of generating RF tone bursts with a rectangular envelope. Sometimes, however, a user may want to use the power amplifier in the system to amplify waveforms from an external waveform generator. By placing the system into Amplifier Mode, the user can bypass the internal signal synthesizer. This document illustrates how to do this and includes a 'Quick Start' procedure.

Bypassing the internal synthesizer also bypasses some of the protections that are in place. Without due caution, the user can end up well outside the safe operating area for the instrument, which will result in damage to the instrument. Following the guidelines in this document will help to ensure safe operation.

Before you get started:

1. Proceed with caution. Bypassing the internal signal synthesizer also bypasses some of the protections. The user can go outside the safe operating conditions of the amplifier, resulting in damage.

2. Using the RPR-4000 in amplifier mode requires an external signal generator, and it is incumbent upon the user to program the signal generator correctly. However, if you need assistance convincing your signal generator to generate the correct signals, then please contact RITEC; we would be happy to assist you.

3. The waveforms shown in this note were taken using a high power, low frequency model of the RPR-4000, which has the following specifications:

- Maximum output power of 15 kW into 50 Ω
- Optimal frequency range of 50 kHz – 500 kHz
- Maximum duty cycle of 0.3%
- Maximum pulse width of 200 μs (0.2 ms)

Instructions for other models for the RPR-4000 will be similar. Critical differences are the maximum duty cycle and the maximum pulse width; the user must respect these limits to avoid damaging the unit.

RPR-4000 Safe Operating Area

Safe Operating Area refers to the combination of duty cycle and pulse width that the RPR-4000 can deliver full power without damage to the instrument.

When using the RPR-4000 normally (i.e., not in 'Amplifier Mode'), several protections are in place to keep the user within the safe operating area of the instrument. The user cannot exceed the maximum pulse width or duty cycle. **However, in 'Amplifier Mode' the user can easily apply a combination of signals that will result in the departure from the safe operating area. This will result in damage to the unit.**

The safe operating area can be conveniently illustrated on a plot of repetition rate vs. pulse width as shown in FIGURE 1. The shaded area represents the combination of repetition rates and pulse widths that have a duty cycle less than 0.3% and a pulse width less than 200 μs.

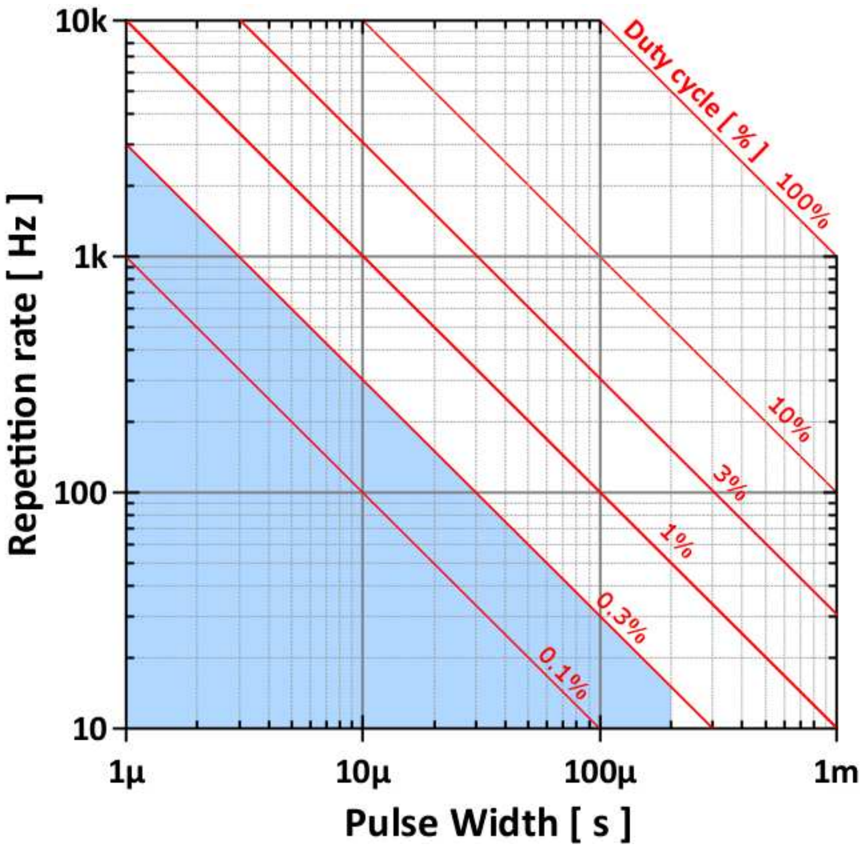

FIGURE 1: The shaded area in the plot of repetition rate vs. pulse width represents the safe operating area for the low frequency (50-500 kHz) high power (15 kW) RPR-4000.

Different models of the RPR-4000 have different safe operating areas, and **it is incumbent upon the user to remain within the safe operating area when using the unit in Amplifier Mode.** Consult the manual for your system or contact RITEC if you have questions.

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CAUTION for gate signal

Always check the gate signal input. A common error is to use a gate signal that has a duty cycle of 50% for the amplifier gate signal. **Do not use a 50% duty cycle signal for the gate input.**

The gate signal is used to turn on the power stage of the amplifier. If the gate signal is long in duration than the pulse width limit for the system (which could be the case if a 50% duty cycle signal is connected to the gate and the repetition rate is low enough), then for each pulse the amplifier will be gated on for the maximum allowed time. This is illustrated in FIGURE 2. While the timing details will depend upon the repetition rate and pulse width limit for the particular setup, it is very easy to inadvertently leave the safe operating area for the system.

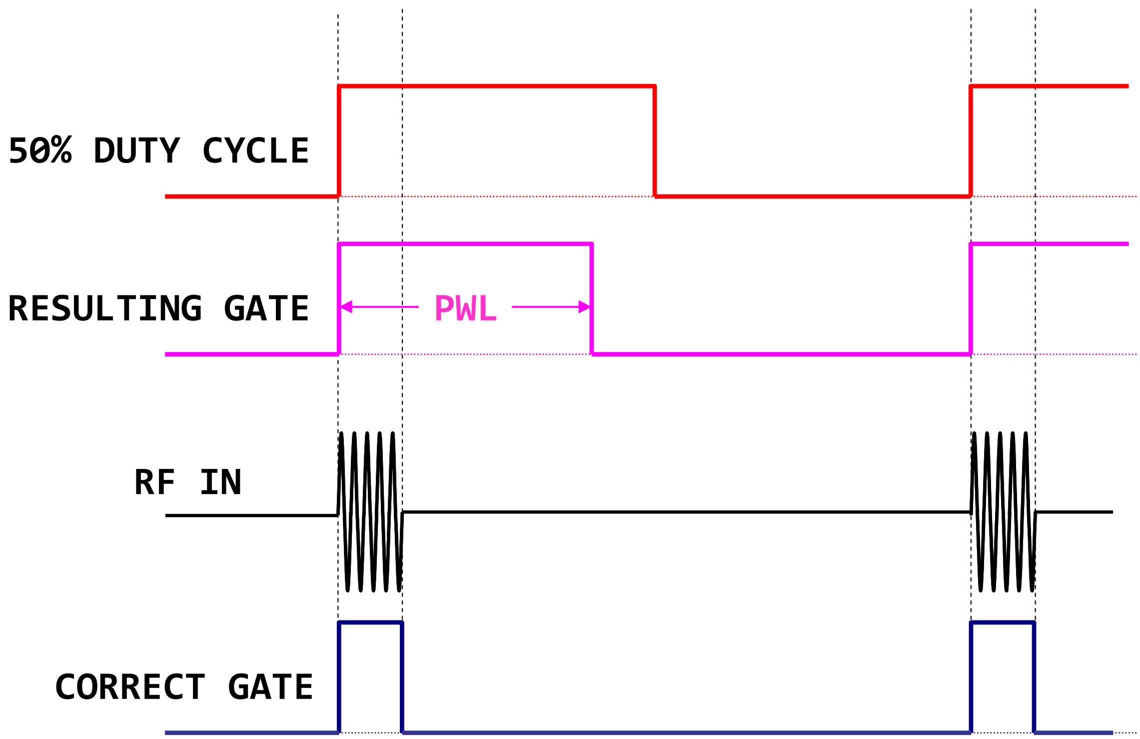

FIGURE 2 Illustration of the result of using a 50% duty cycle for the amplifier gate signal. Depending upon the values of the repetition rate and pulse width limit for the system, if the gate signal has a duty cycle of 50%, then for each pulse the amplifier will be gated on for the maximum amount of time, even though the RF input signal may be much shorter than this. This makes it very easy to exceed the duty cycle limit for the system.

There is a hardware protection that will catch this error and shut down the unit. However, this protection measure is based on a thermal fuse, which will only catch the fault a limited number of times.

Amplifier Mode 'Quick Start' Procedure

The following procedure will help the user successfully use the RPR-4000 to amplify external waveforms without damage to the instrument or equipment.

1. Set up the external function generator

Two input signals are required:

1. RF input – this is the signals to be amplified.
2. Gate – this is the signal that turns power stage of the amplifier

FIGURE 3 shows the basic requirements for each input signal. It is important to understand that the power amplifier in the RPR-4000 is a 'gated amplifier'. In this context the term 'gated' means that the amplifier is enabled only for a short period of time. This is different from many power amplifiers which are on and amplifying continuously. By gating the amplifier on for only a short fraction of the time, the power consumed is greatly reduced and the thermal management becomes much simpler.

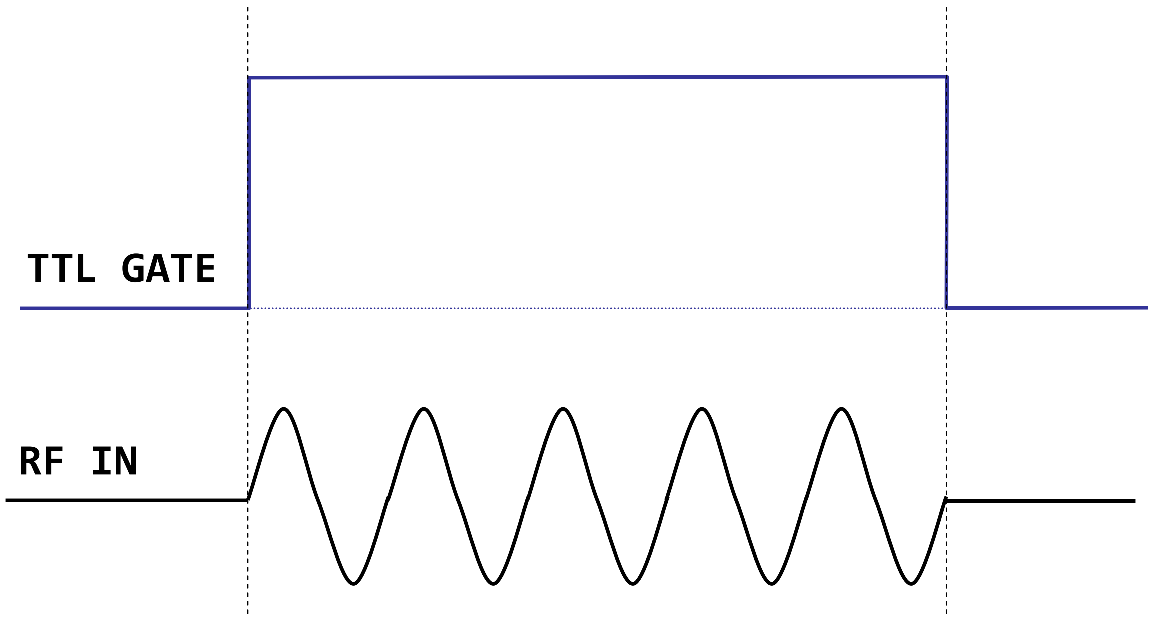

FIGURE 3 Input signals required for operation of the RPR-4000 in Amplifier mode. The RF IN signal is the signal to be amplified. The amplitude should be 800 mV to 1 V peak to peak maximum. The Gate signal should be a positive going TTL level logic signal that goes high at the start of the RF burst and goes low at the end of the burst.

There are many signal, function, and waveform generators available to the user, each with its own capabilities and limitations. For those who are either first time RPR-4000 users or new to electronics, it is strongly advised to start with simple waveforms. Once you have managed to program and amplify simple waveforms then proceed to more complicated ones if desired.

2. Verify signals on oscilloscope scope

Before connecting the signals to the RPR-4000 and attempting to amplify anything it is prudent to directly view these signals with a suitable oscilloscope or digitizer and verify that you have indeed programmed the signal generator correctly.

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FIGURE 4 shows an oscilloscope screen capture of the input signals for this example. The gate signal goes high at the start of the RF burst and low at the end of the burst to be amplified.

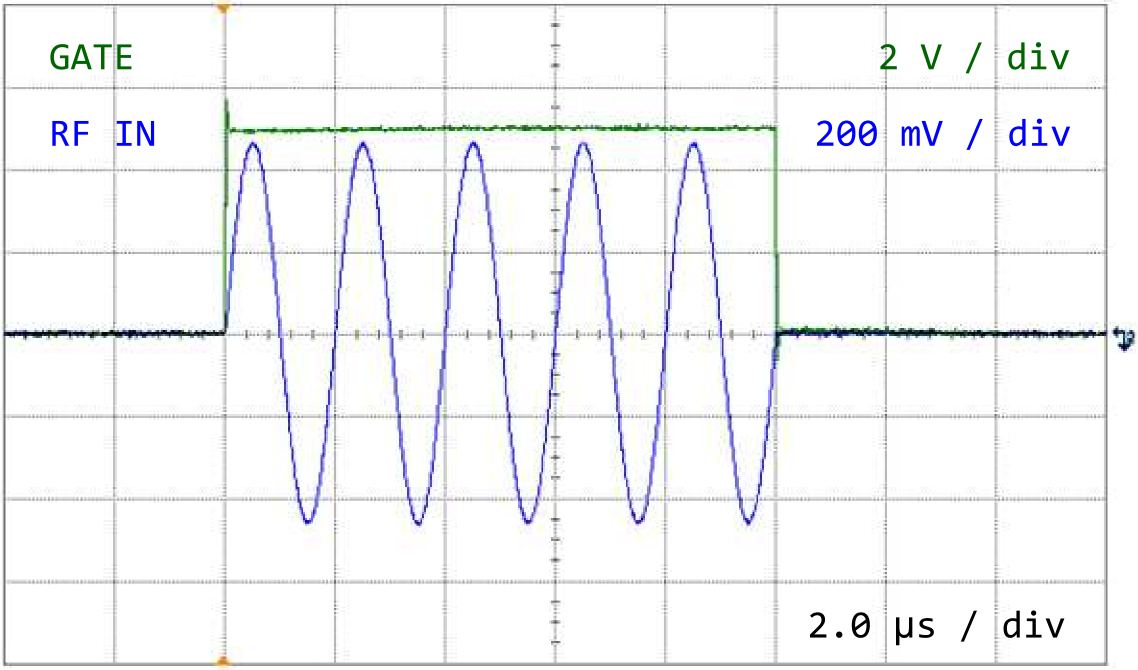


FIGURE 4 Screen capture of the input signals for using the RPR-4000 in Amplifier mode. The RF waveform is a 5 cycle tone burst with a center frequency of 500 kHz.

There is an even greater variety of oscilloscopes, digitizers, and waveform viewing devices available to the user, each with its own characteristics and user interface.

The one thing that gives users new to electronics the most difficulty seems to be trigger settings. Be certain to set the trigger source to be the channel/connector that the GATE signal is connected to, and set the trigger level to be in the range of 2 to 3 V.

3. Program the RPR-4000

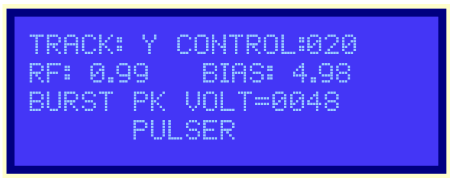
To put the RPR-4000 into Amplifier Mode, use the keypad interface to change the following parameters:

Page (1): Set ‘FREQ’ to 00.000000 MHz’

This disables the internal signal generator.

Page (2): Set ‘TRACK’ to Y and CONTROL to 020

These controls are for the gain of the amplifier, or the output level control. Set this to something low when first starting, and then increase once you see an output on the oscilloscope.



Page (4): Set ‘TRIG’ to EXT

This enables the RPR-4000 to accept external gate signals.

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4. Make the connections

Make the connections shown in FIGURE 5. Some further comments about each connection are given below:

Setting (1): High Voltage Control set to Disable

Before making any connections, verify that the high voltage control is set to Disable.

Connection (2): Function generator out to "CW IN"

The recommended maximum amplitude for this signal is 1 V peak to peak terminated into 50 Ω. Do not go above 1 V pp levels at the input, otherwise significant distortion may appear in the output as the low level stages of the amplifier are overdriven.

Connection (3): Function generator gate signal to "AMP GATE IN"

It can be a challenge to convince a signal generator to generate the required gate signal. Some signal generators have a gate signal available as an auxiliary output. Another option is to use a dual channel function generator and program the second channel to generate the necessary gate signal.

Connection (4): Oscilloscope trigger connection

FIG. 5 shows the gate signal connected to a BNC 'T' connector and then split to the RPR-4000 and the oscilloscope trigger input, which can be either an unused channel on the oscilloscope or an 'EXT' trigger input connector. There are alternative methods to trigger the scope; the method shown in the figure is relatively robust and stable.

Connection (5): "RF PULSE MONITOR" to oscilloscope input

The signal from this port on the RPR-4000 is a scaled down version of the high voltage output. This provides a means of 'seeing' what the amplifier is doing without using a high voltage probe. Connecting "HIGH POWER RF PULSE OUT" directly to an oscilloscope will result in damage to that oscilloscope.

Connection (6): "HIGH POWER RF PULSE OUTPUT" to suitable load

Depending upon your application you may or may not need a resistive termination. When getting started using the RPR-4000 for the first time (or when using a particular transducer with the RPR-4000 for the first time) it is a good idea to use a resistive termination like an RT-150.

Connection (7): Transducer connection

When first getting started it may be helpful to only connect a resistive termination such as an RT-150 to the high voltage RF output of the RPR-4000 and adding the transducer later once the performance of the electronics has been verified.

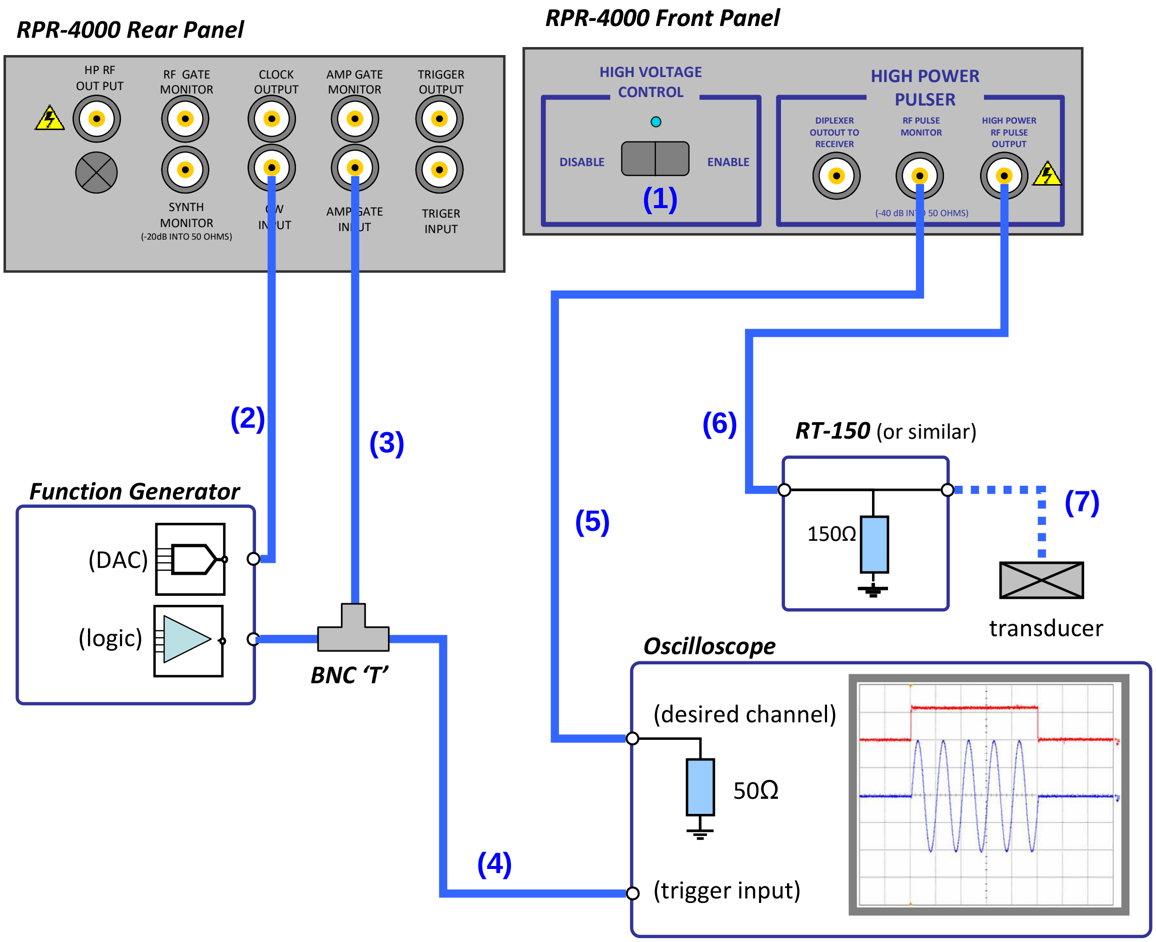

FIGURE 5: To use the RPR-4000 in Amplifier Mode, you will need a suitable function generator, an oscilloscope, and a load. Make the connections shown in blue. Individual connections are numbered and discussed in the text.

5. Check the connections

BEFORE turning on the HV, double check the connections, especially the connections carrying high voltage RF pulses. The output of the RPR-4000 amplifier is capable of damaging oscilloscopes, pre-amplifiers, and any connection not rated for high voltage pulses.

A good practice is to physically trace all the HV connections from the output "HIGH POWER RF OUTPUT" to wherever it is terminated, usually a transducer **BEFORE** turning on the amplifier.

6. Turn on High Voltage power supply

Change the rocker switch on the front panel labeled "High Voltage Control" to the Enable position. The blue LED should light up.

7. View monitor signal on scope

The RPR-4000 is capable of generating high voltage pulses that can damage oscilloscopes. An RF monitor port is supplied to conveniently view these high voltage signals without need of external attenuators or probes. The monitor signal on the RPR-4000 is derived from a resistive divider. When this port is connected into an oscilloscope input and terminated into 50 Ω, then the signal present at this port is

100 times smaller (-40 dB) than that present at the HV output port. Typical waveforms are shown in FIGURE 6 for the case of amplifying a 5 cycle tone burst with a center frequency of 500 kHz.

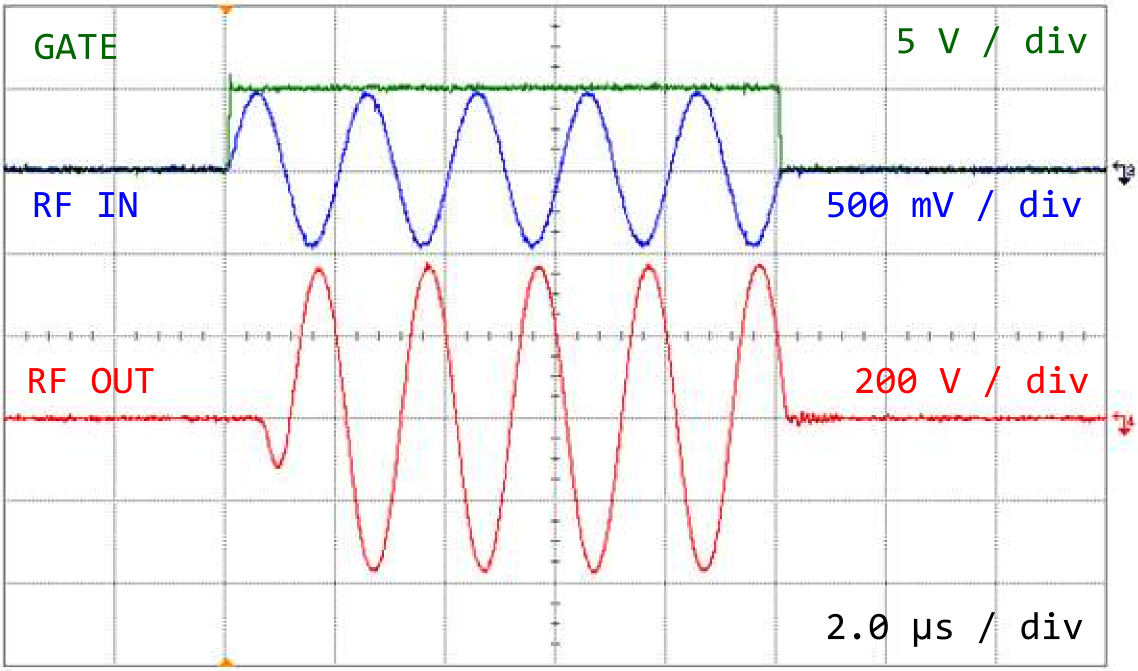

FIGURE 6: Typical waveforms for the example described in the text. The parameter CONTROL has been set to 20 in the Keypad interface, and the amplifier is delivering approximately 750 Vpp to the load.

Some things you may notice at this stage:

- The amplifier takes a finite time to fully turn on. After the arrival of the gate signal, it takes approximately 1 µs for the power gain stage of the amplifier to be fully active. For most applications this is not an issue, but for high speed and short pulse applications this can cause problems. See "Adjustments to Gate Timing" below for more guidance on making adjustments to the timing of the gate signal.

- The amplifier is an inverting amplifier. Again, for most applications this is not an issue.

8. Make desired adjustments

At this time you can make adjustments to either the RPR-4000 or the signal generator to achieve the desired waveform. FIGURE 7 shows typical waveforms after making an adjustment to the output amplitude using the keypad interface. For the example that we have been following here, the parameter named CONTOL accessed using the Keypad interface has been increased from 20 to 80, and the amplifier is delivering over 2000 V peak to peak into this load.

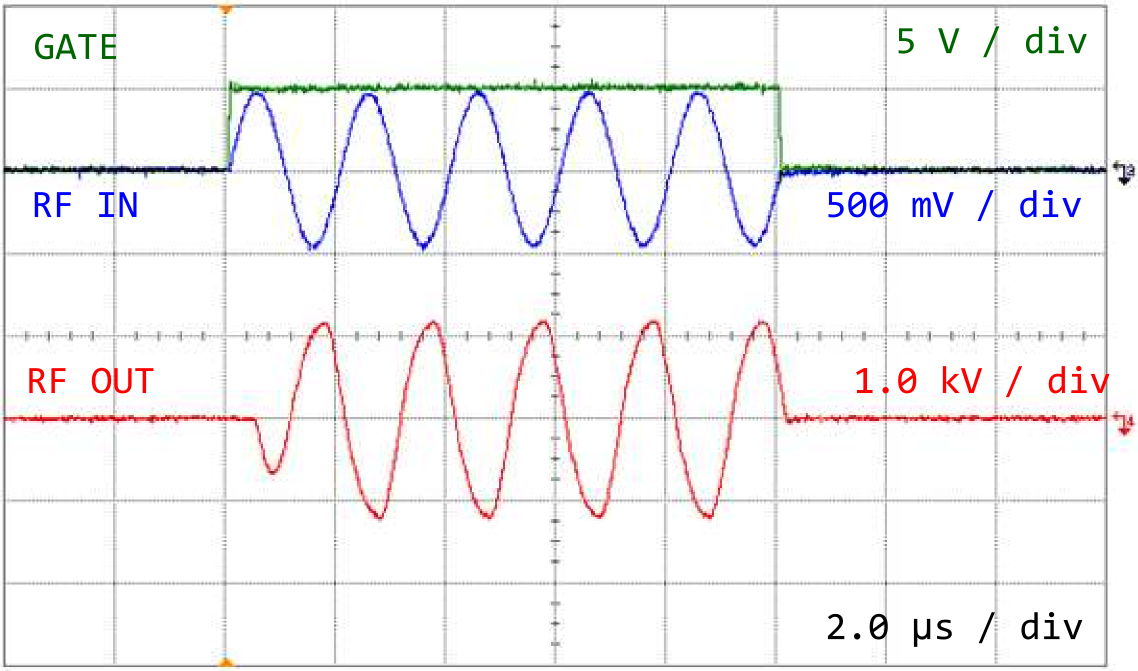

FIGURE 7: Same as FIG. 6, but the output has been increased by using the CONTROL parameter in the Keypad interface menu. The amplifier is now delivering over 2000 Vpp into the load.

Some examples of other adjustments that can be made are shown in the remainder of this note, with examples and guidelines to help the user understand the amplifiers capabilities and limitations.

Always view the RF signal monitor when making adjustments. This is especially important when changing either the frequency or pulse-width, since the resulting peak excitation amplitude can change with either of these parameters.

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Examples of typical adjustments

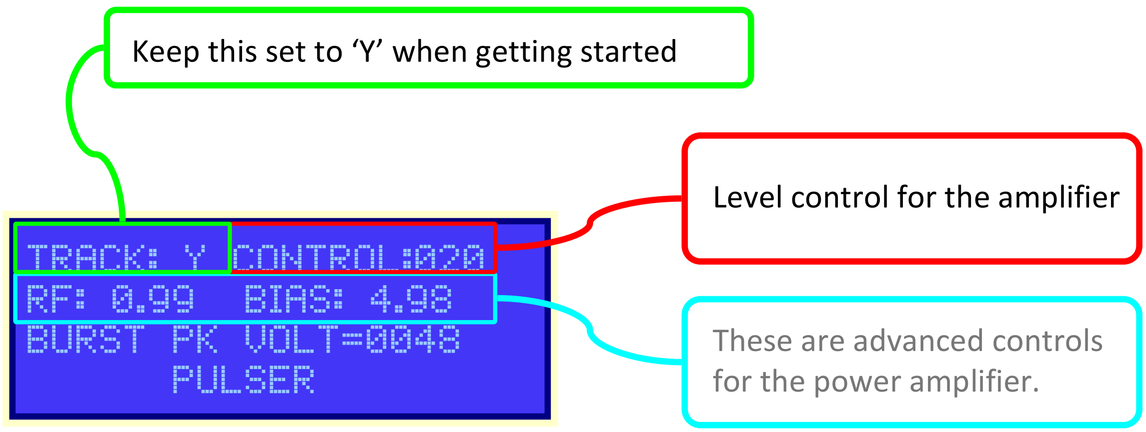
In Amplifier Mode, the RPR-4000 is used in conjunction with an external signal generator, so adjustments may be made to either instrument in order to optimize the generated waveform. Some comments on adjusting the output level and fine adjustments to the relative timing of the input signals are given below.

Controlling amplitude

There are three methods of controlling the output amplitude:

1. Using the Level Control on the Keypad interface (or remotely by RS-232)
2. Adjusting the input amplitude from the signal generator
3. Using high power attenuators

The power amplifier in the RPR-4000 is a variable gain amplifier. The gain is adjusted using the parameter labeled 'CONTROL' on menu 2 of the key pad interface. We strongly recommend that you follow the settings listed in the 'Getting Started' procedure. FIGURE 8 shows typical waveforms when increasing the output using the Keypad interface.



Occasionally, lower power outputs are desired. One way to achieve this is by reducing the control down to 5 or less. However, the output level can also be adjusted by simply reducing the amplitude of the RF input signal from the signal generator.

To achieve the cleanest output waveform, place a high power attenuator A trial and error approach is the easiest way to achieve the best results. Typical waveforms are shown in FIGURE 9.

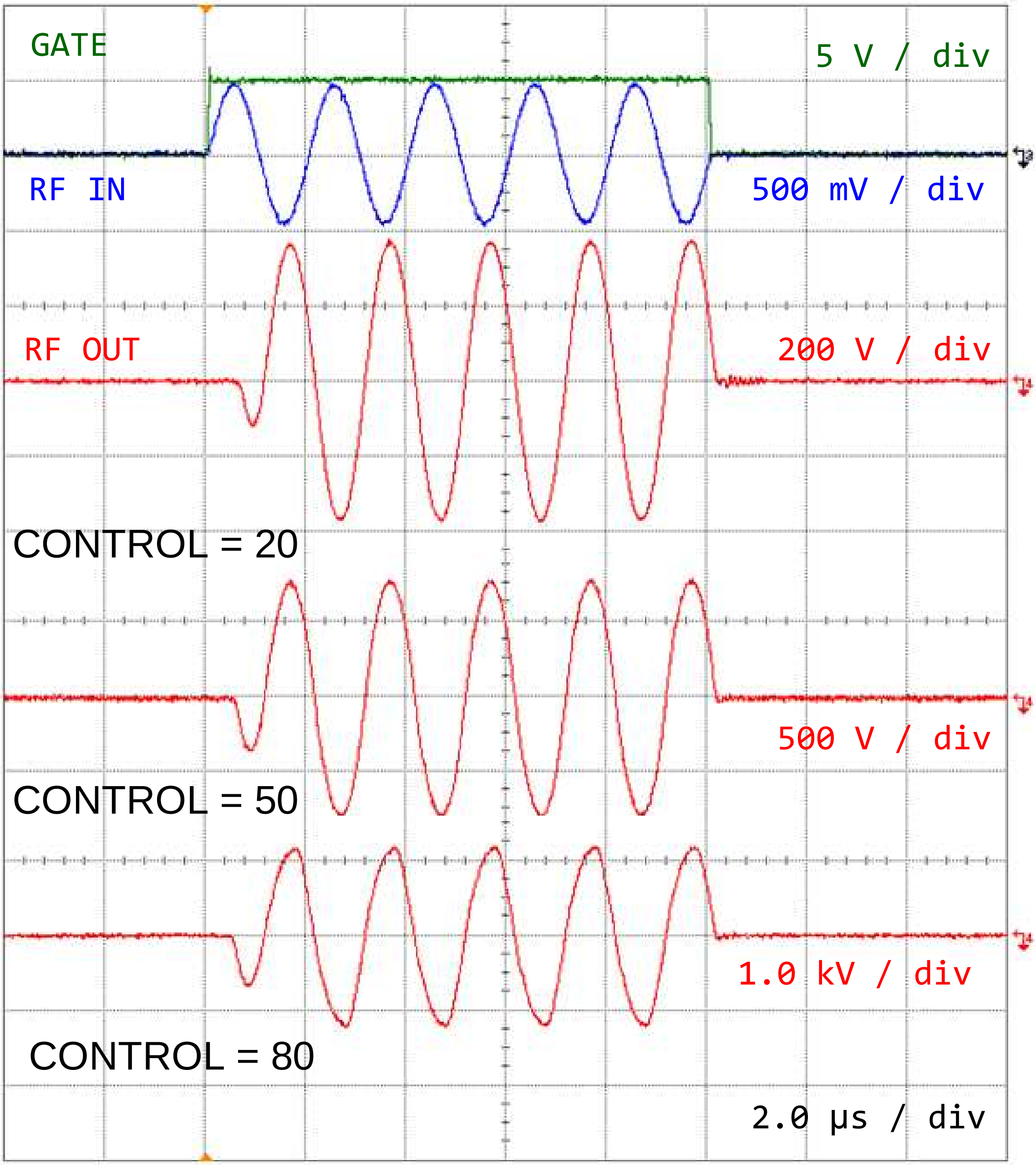


FIGURE 8: Typical waveforms at 500 kHz for a low frequency, high power RPR-4000 at CONTROL of 20, 50, and 80. We recommend using the front panel adjustment to achieve the cleanest waveforms. A typical RPR-4000 will have a 26 dB (or a factor of 20 for output voltage) adjustment range using the front panel interface.

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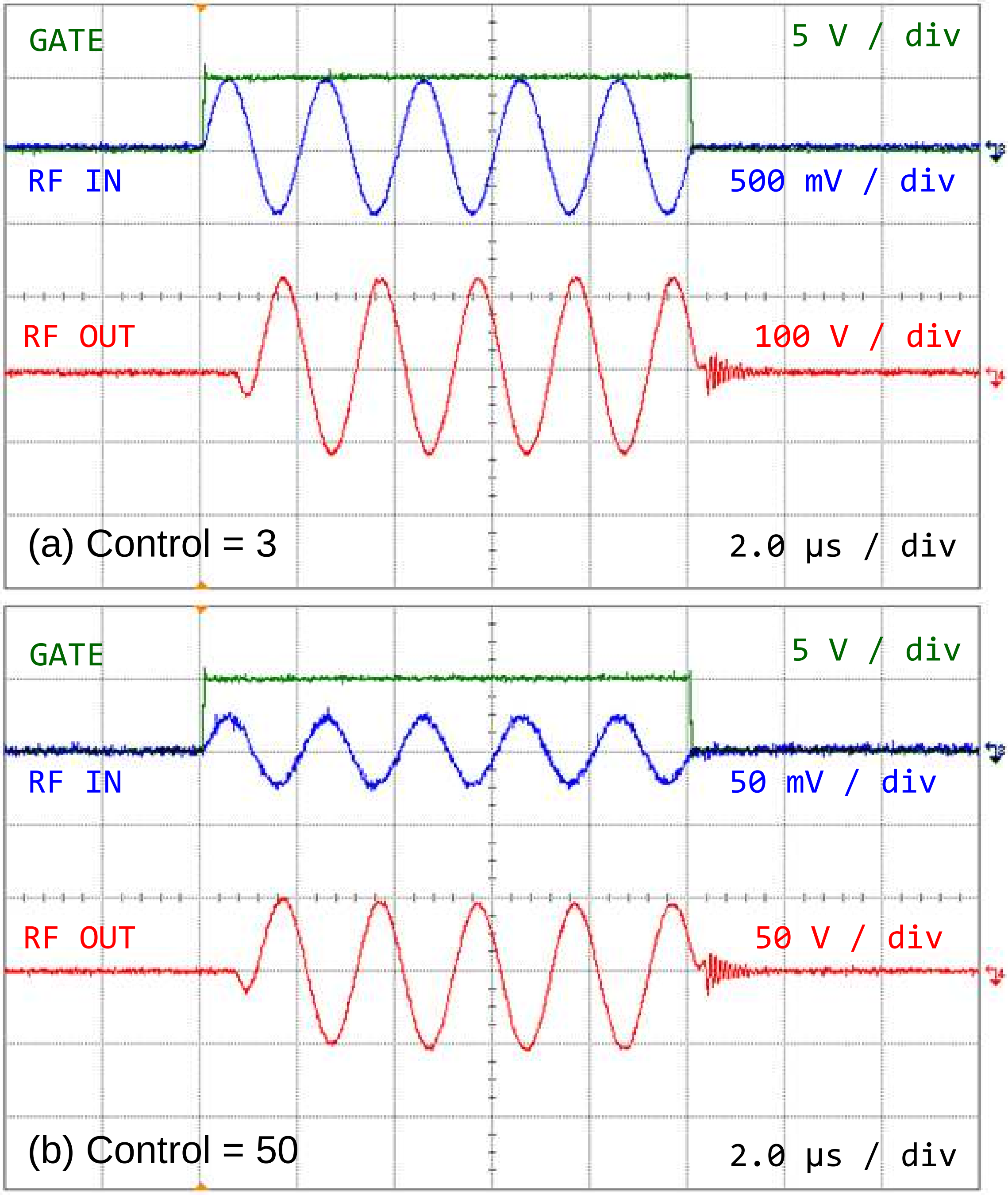

FIGURE 9: Typical low power waveforms at 500 kHz for a low frequency, high power RPR-4000 (a) 120 V peak to peak output achieved using the keypad interface (CONTROL = 03) and (b) 100 V peak to peak output achieved by reducing the amplitude of the RF Input signal to 100 mV pp.

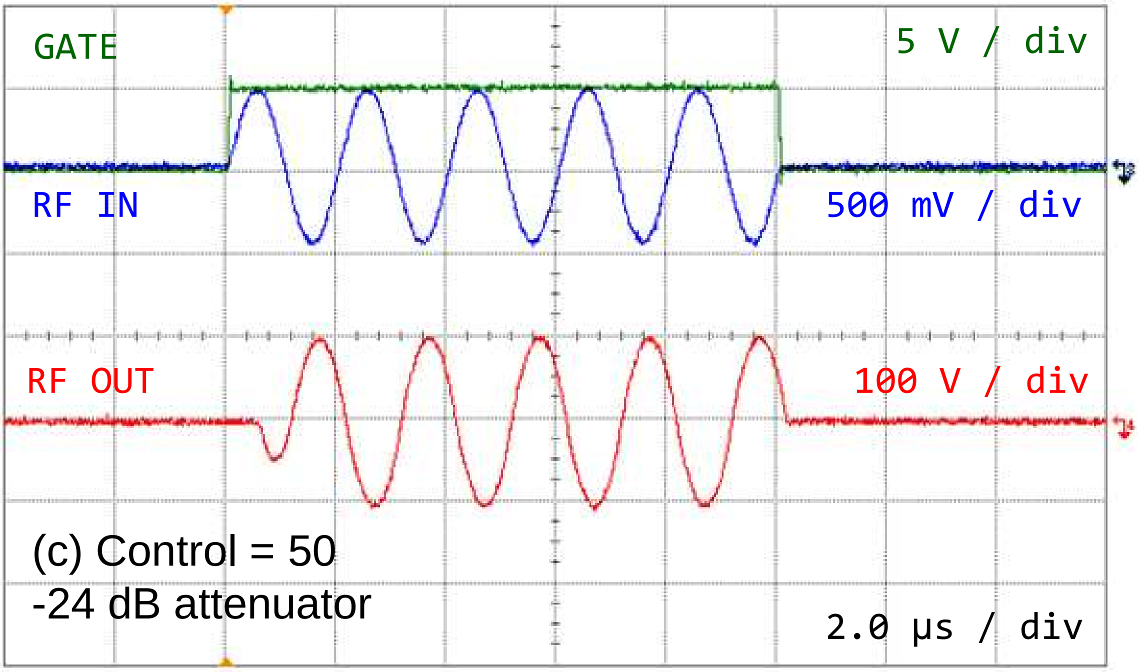

FIGURE 9 (continued) Typical low power waveforms at 500 kHz for a low frequency, high power RPR-4000 (c) Typically the cleanest outputs are achieved for control settings of 20-50 and through the use of a high power attenuator.

Guidelines for level control:

- Use the keypad interface (or remote interface over RS-232) for level control unless you have a good reason not to (see below)
- To obtain the cleanest low voltage outputs, use an attenuator on the high voltage output.
- Small adjustments to output level can be most easily achieved by changing the amplitude of the signal RF In.

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Adjustments to gate timing

One aspect of the gated amplifier not discussed above is its finite turn-on and turn-off time. After the gate signal transitions from low to high it takes the amplifier approximately 1.0 µs to be fully enabled. If the user is unaware of this finite turn-on time then some confusion may result, especially in situations involving short pulse widths or high frequency operation.

The relative timing of the gate signal to the RF input signal can be adjusted to compensate for the finite turn-on and turn-off times of the amplifier. FIGURE 10 is a diagram showing the definitions of 't-on' and 't-off'. **For the most faithful amplification of the input signal, the recommend value for 't-on' is 1.0 µs, and t-off in the range of 0 to 100 ns.** The optimal values will depend upon the frequency, input waveform, and in some cases output level and load impedance; some trial and error may be required to find the optimal values for a given setup.

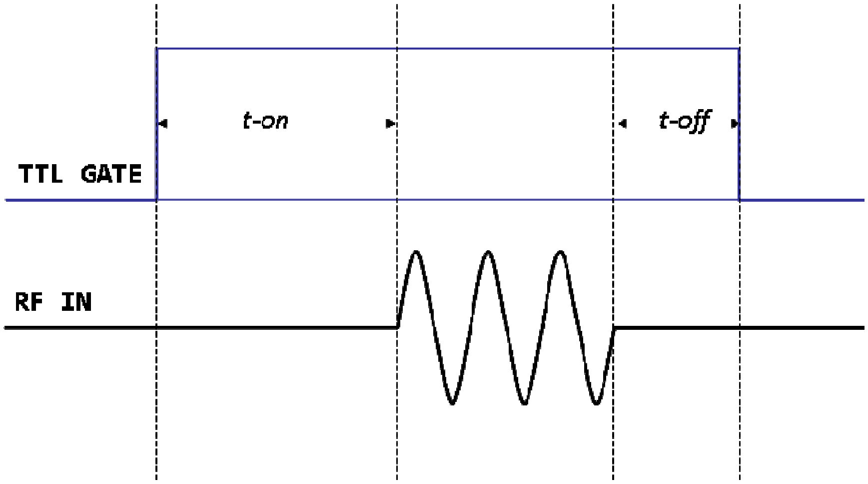

FIGURE 10: Definitions of the time delays 't-on' and 't-off'. The fidelity of the output signal to that applied to the RF input can be improved by making adjustments to the times 't-on' and 't-off'.

Some more advanced signal generators (or true arbitrary waveform generators) will allow programming outputs with non-zero values for t-on and t-off. An alternative is to use a dual channel function generator, with, for example, channel 1 used to synthesize the RF signal of interest and channel 2 dedicated to generating an appropriate gate signal.

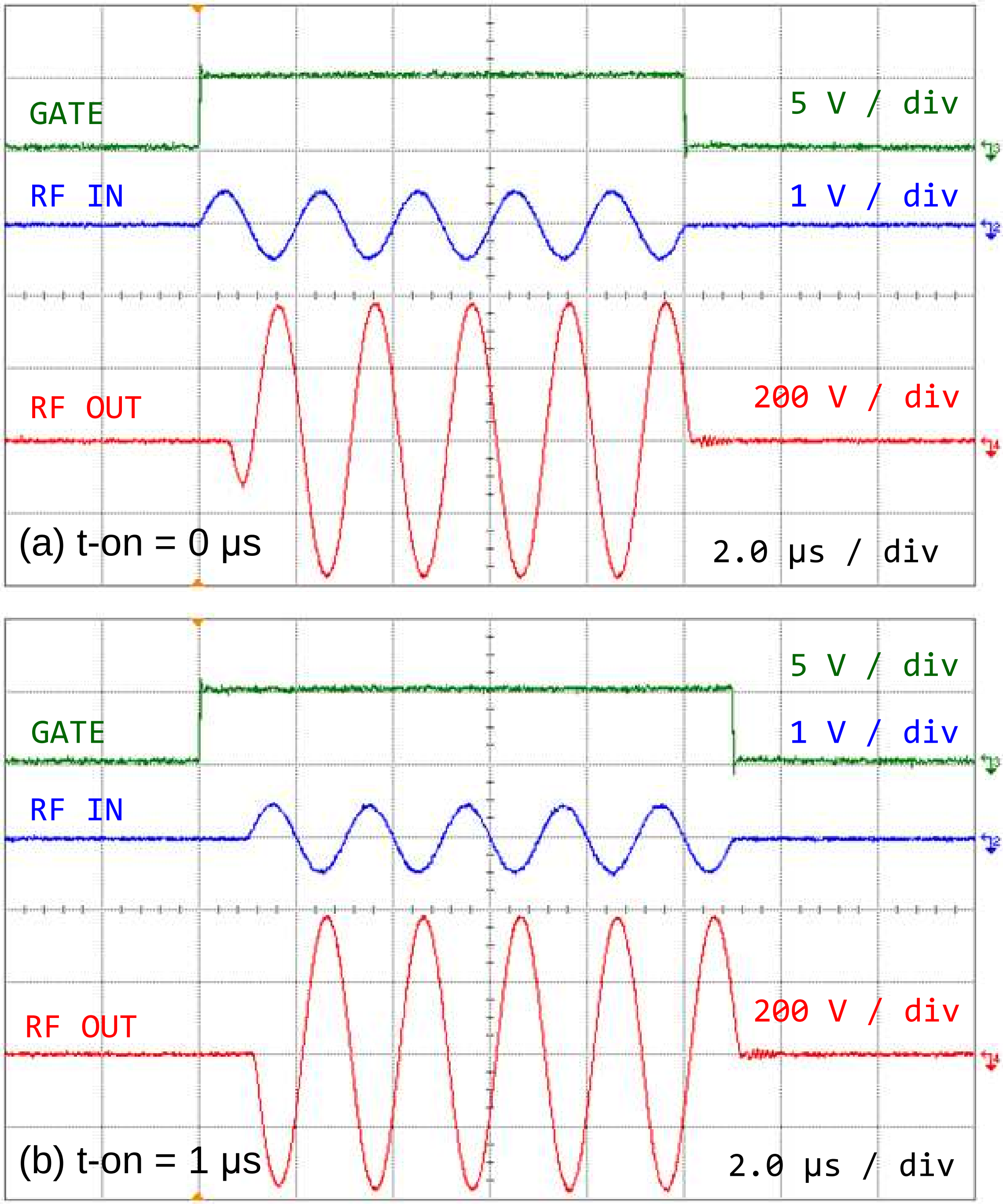

FIGURE 11: Typical output signals for amplifying a 5 cycle tone burst at 500 kHz. (a) the signals 'GATE' and 'RF-IN' start at the same time, and the amplifier 'misses' the first half cycle or so, (b) introducing a delay between the GATE and RF-IN of 1.0 µs allows the amplifier to be fully enabled by the time the RF input signal arrives.

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FIGURE 11 shows some typical waveforms for amplifying a 5 cycle tone burst with a center frequency of 500 kHz with (a) t-on = 0 and (b) t-on = 1.0 µs. With no delay between the RF and the gate signal the amplifier ‘misses’ the first part of the burst, since it takes about this much time for the amplifier to be fully gated on. With a delay introduced between the gate low to high transition and the start of the RF burst, the output faithfully follows the input and all 5 cycles are amplified.

Adjustments to the time ‘t-off’ are normally not required, but some situations may show improvement after a small adjustment (on the order of 100 ns) to the time t-off. As an example, pulse-echo measurements (using the same transducer for both transmission and reception) may show an improved recovery time of the received signal after the parameter ‘t-off’ is optimized. For more information please contact RITEC.

Amplifying arbitrary waveforms

The example waveforms shown above were all single frequency sinusoidal bursts. However, the RPR-4000 can also be used to amplify arbitrary waveforms, which may be of more interest and utility. The procedure for amplifying arbitrary waveforms is the same as that given above. Some additional points to keep in mind when amplifying arbitrary waveforms:

1. The amplifier is an inverting amplifier
2. Internal circuitry enforces the maximum pulse width
3. The gain of the amplifier is frequency dependent.
4. The power amplifier is not a DC amplifier

To assist the user, example waveforms illustrating each of these points are shown below.

1. The amplifier is an inverting amplifier

The power amplifier acts as an inverting amplifier, which is illustrated in FIGURE 12. The inversion occurs at the input of the RF power amplifier circuitry. For most pulsed ultrasound applications this is not an issue, but if it is then the easiest way to handle this is to invert the input waveform.

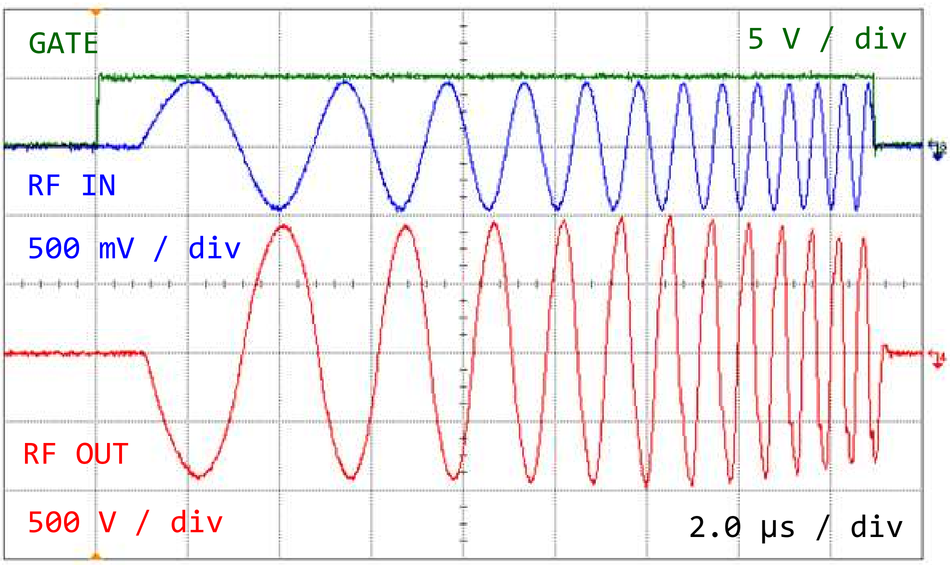

FIGURE 12: Typical waveforms for a chirp waveform. The output has been inverted with respect to the input waveform.

2. Internal circuitry enforces the maximum pulse width

If you try to exceed the maximum pulse width for the instrument, then the pulse width limiter circuit will be activated. This will be clearly visible in the output waveform because the RF output will cut off at approximately 1.1 times the instruments specified maximum pulse width. Typical waveforms are shown in FIGURE 13.

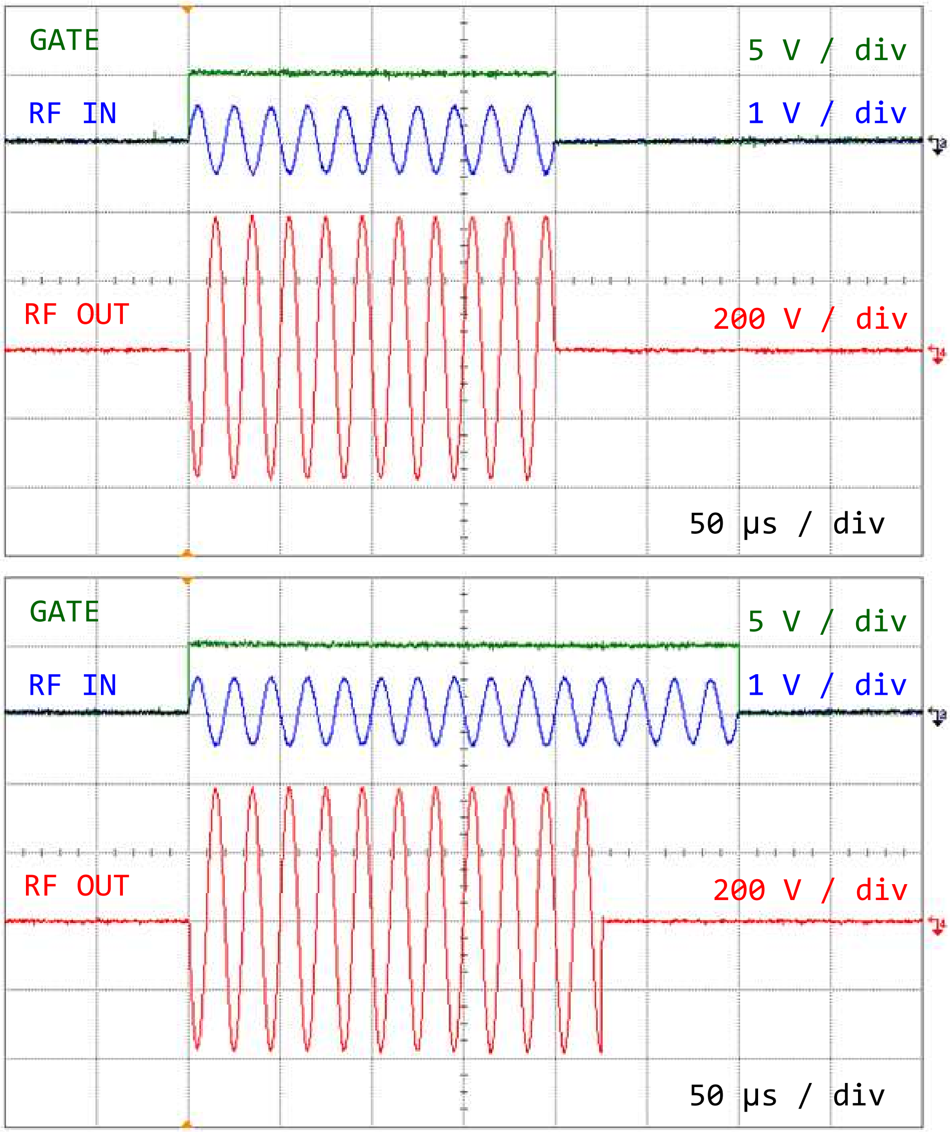

FIGURE 13: A long pulse will result in activation of the pulse width limiter. TOP: a 200 µs burst is amplified without issue. BOTTOM: A pulse longer than the limit of 200 µs limit results in a truncated output.

3. The gain of the amplifier is frequency dependent.

Each RPR-4000 has a frequency range over which it is guaranteed to generate its maximum specified output power. Outside of this frequency range the unit will develop usable power, but at reduced amplitude.

A. Low frequency saturation effects

The output of the amplifier in the RPR-4000 is transformer coupled. As the frequency goes below the specified low frequency point, saturation effects may become apparent in the output. An example that illustrates the low frequency saturation is shown in FIGURE 14. This effect is both amplitude and frequency dependent. The start frequency of the chirp signal is 25 kHz, which is outside the specified range of the instrument (50-500 kHz). At low output amplitudes (FIG. 14a) the amplifier shows good fidelity to the input, but as the amplitude is increased (FIG. 14b) saturation effects are visible.

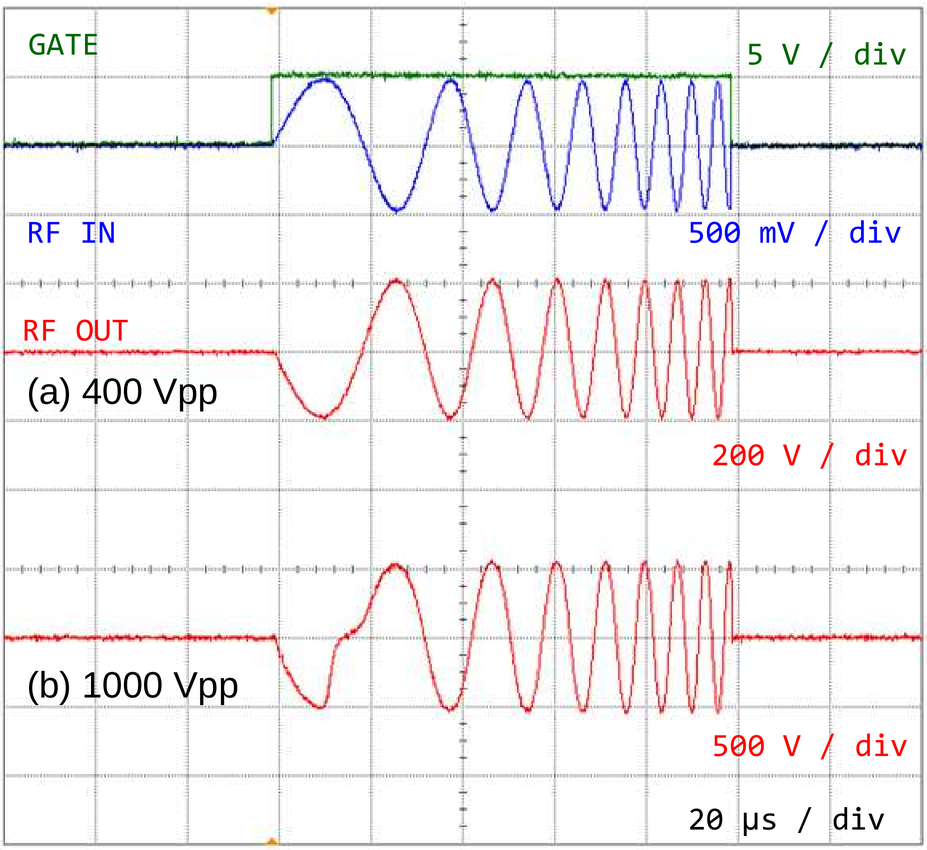

FIGURE 14: Example of low frequency saturation effects, which are both frequency and amplitude dependent. The input is a chirp with a start frequency of 25 kHz. (a) At 400 Vpp amplitude, the amplifier recreates the input without issues, however, at (b) 1000 Vpp amplitude, the output transformer shows clear signs of saturation.

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B. High frequency effects

The gain of the amplifier falls off with increasing frequency. This is illustrated in FIGURE 15 which shows the typical response for an input that is a chirp signal with a start frequency of 250 kHz and stop frequency of 2.5 MHz, with the output set such that about 1800 Vpp are being delivered to the load. Over this range, the output clearly starts to fall with frequency, and harmonic distortion becomes apparent at the middle frequencies. This is a bit of an extreme example, since most ultrasonic transducers cannot accommodate a 1:10 frequency range input. FIGURE 16 is similar to FIG. 15, but the frequency has been increased from 500 kHz to 5 MHz, and the output has been reduced to 1000 Vpp. The amplifier output falls by about 6 dB over this range.

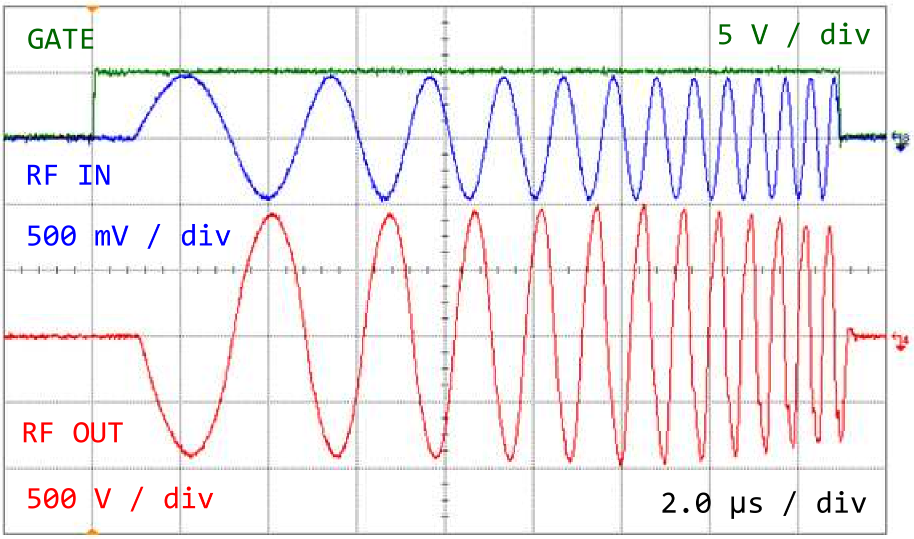

FIGURE 15 Chirp performance, 250 kHz to 2.5 MHz, at almost full output power. The output shows signs of decreasing in the upper range, falling about 3 dB by the end of the burst.

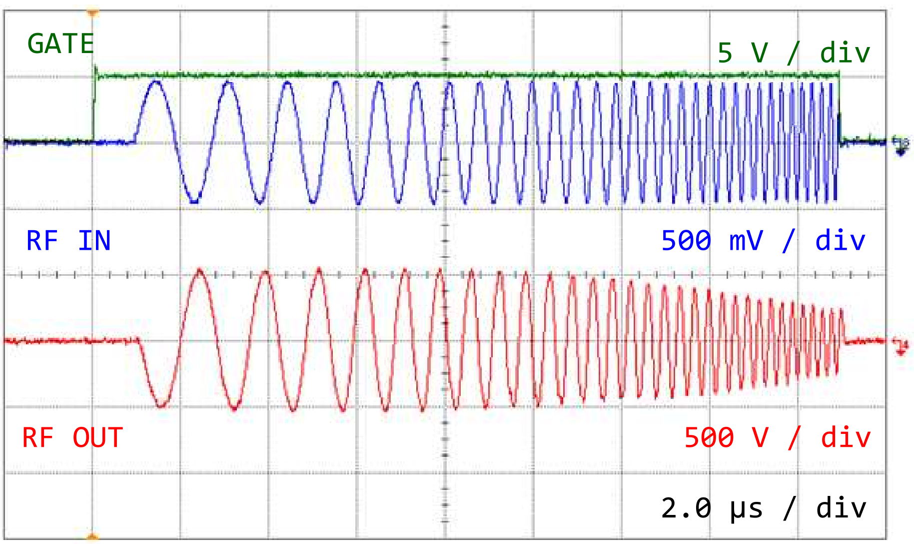

FIGURE 16 Typical performance for a 500 kHz to 5 MHz chirp at 1000 Vpp output level. The output shows signs of decreasing in the upper range, falling about 6 dB by the end of the burst.

4. The power amplifier is not a DC amplifier

Attempting to amplify waveforms with a non-zero DC component will result in saturation effects. This is illustrated in FIGURE 17 by using a rectified sine wave as the input waveform. After 3 peaks the output transformer starts to saturate and the output no longer follows the input. The saturation effects are both time and amplitude dependent.

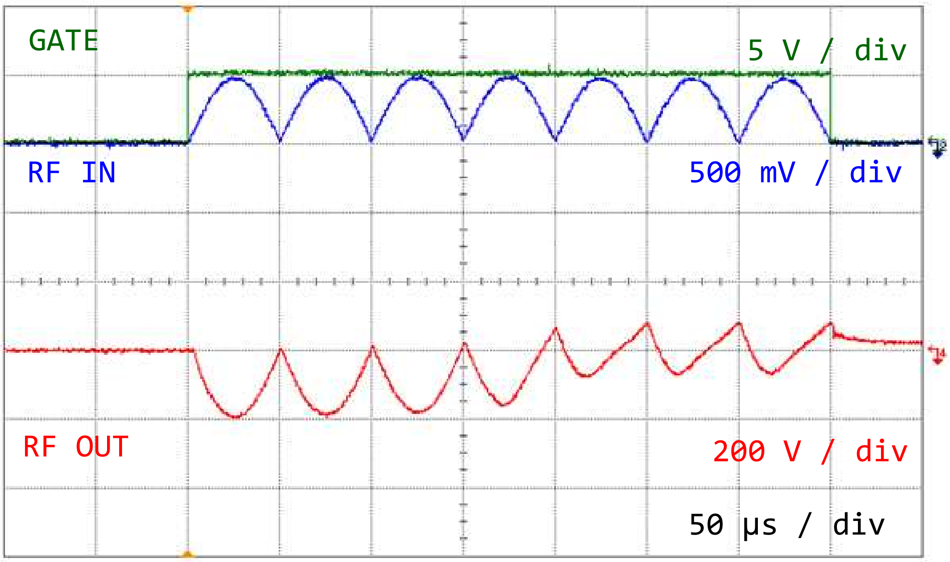

FIGURE 17 Typical output when the input has a non-zero DC component.

Final comments

The RPR-4000 was designed to be a robust pulser-receiver for pulsed ultrasound applications. To accommodate user's requests, the power amplifier of the instrument has been made available. By putting the unit into Amplifier Mode as described, the user can amplifier their own waveforms. However, this mode bypasses some of the internal protection measures that are in place. Following the guidelines described above will help to prevent any damage to the instrument or connected equipment. In summary:

- Always verify the output of the signal generator BEFORE connecting it to the RPR-4000.
- Always double check the connections BEFORE enabling the High voltage control switch on the front panel.
- Always monitor the amplifier output by either using the burst monitor signal or an appropriate oscilloscope probe.
- Always start with the output level control set between 10 and 20, and work up to the desired amplitude.

If you need help please do not hesitate to contact RITEC.

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