Sidebands Are Not Necessary

H. R. Walker
Pegasus Data Systems
pegasusdat@aol.com

Abstract:

Conventional wisdom holds that sidebands are absolutely necessary because all of the modulation is in the sidebands. It has been shown that with 'Ultra Narrow Band' modulation methods, and later with AM pulse tests, that this is not a correct statement for the transmission or reception of AM pulse modulation. The components of the Fourier spectrum are separable and the carrier can be used alone. Sidebands at the transmitter are necessary in RADAR type systems because the available filters cannot remove them at the transmitter, but they are not necessary in the receiver where zero group delay filters having a very narrow bandwidth are available. Some other pulse systems having good frequency control may be able to remove them with filtering at the transmitter.

The filters used with UNB have near zero rise time and group delay so that the pulse response has no loss of waveshape. The pulse at the output is the same pulse as that at the input.

Sidebands vs Carrier:

It is well known that an AM signal contains a carrier plus sidebands. See equation 1. The carrier contains ½ the peak voltage and the summed contra rotating sidebands add to double or cancel the peak voltage with 100% modulation. It can be shown by the simple means of removing the carrier from a pulsed signal that the sidebands contribute 50% of the energy.

Similarly, using the special near zero group delay filters, reducing or removing the sidebands causes a detected voltage loss of 50%. All of the necessary information to detect an On/Off AM pulse is present in the carrier alone. This has been proven to be the case with 'Ultra Narrow Band' digital modulation (Ref. 1) since 1998. The present paper shows near perfect reception without usable sidebands for AM pulses. The method does not work for ordinary AM audio.

Advantage of 'No Sideband' Transmission and Reception:

With AM pulses, as in RADAR when the sidebands are removed, only the carrier is transmitted, and the bandwidth required is greatly reduced. The signal to noise ratio (SNR) is directly proportional to the receiver filter bandwidth required. An improvement in the SNR of 30 dB or more can be obtained by removing the sidebands with a narrow bandwidth zero group delay filter in ON/OFF AM pulse transmission. The method can also be used to extend the range of UWB signals

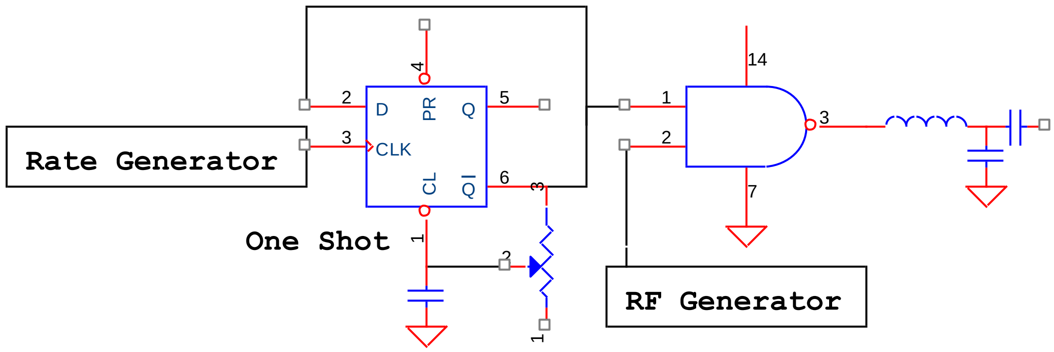

Figure 1. Test Pulse Generator. 48 MHz carrier and 500 nanosecond pulse with 100 % amplitude modulation were used.

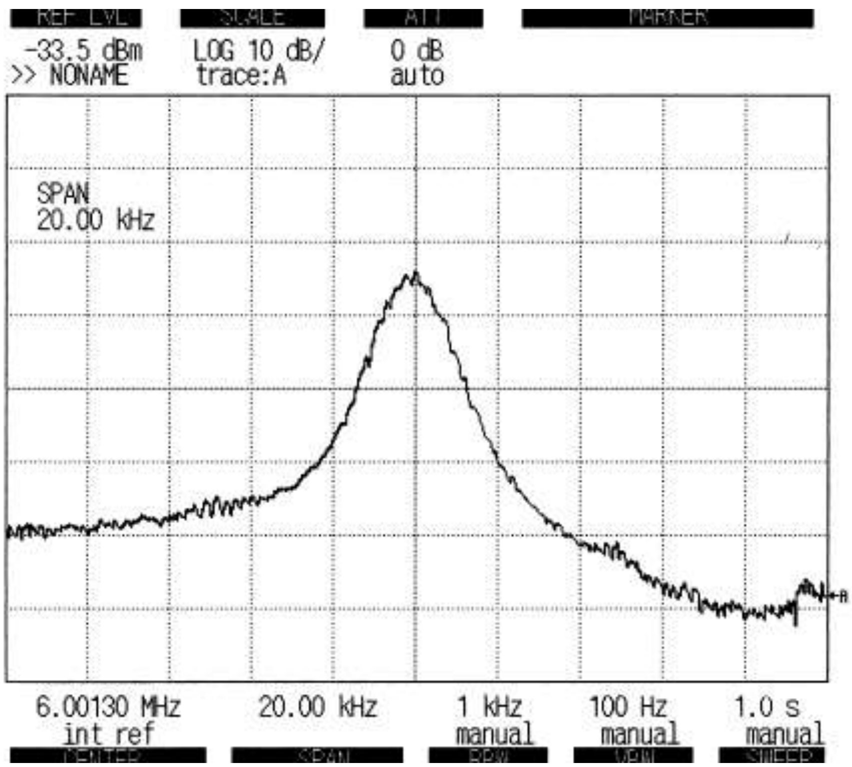

Figure 2. Swept Response of one stage of the series emitter filter. The actual 3 dB bandwidth is much narrower than this plot shows. The spectrum analyzer RBW setting is too broad. The actual 3 db bandwidth is approximately 1/100,000 the filter frequency. (500 Hz for a 50 MHz filter). These filters can be cascaded to increase the sideband rejection.

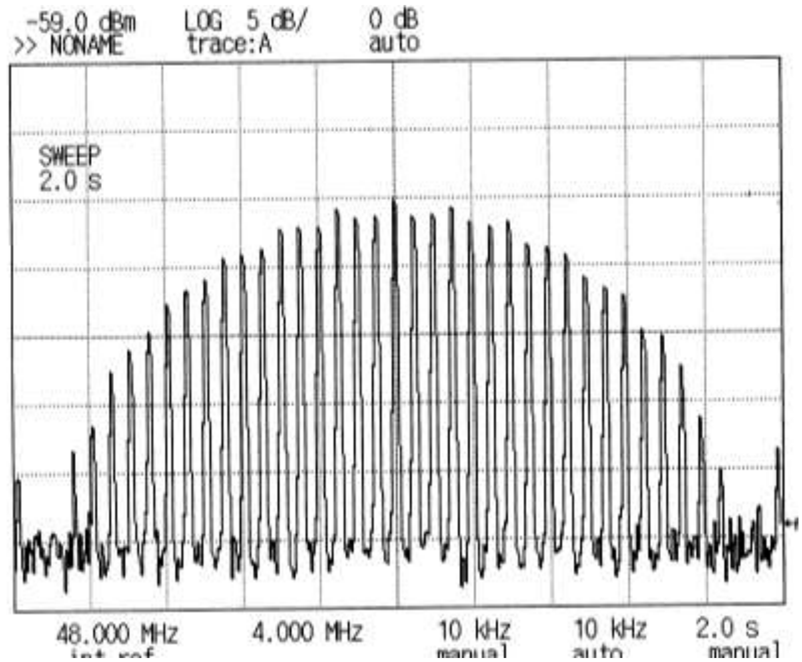

Figure 3. The Fourier sinx/x spectrum at the output of the test apparatus showing the Sinx/x envelop and 2π/T sideband frequency spikes prior to any zero group delay filtering. The number and spacing of these spikes depends upon the repetition rate and the pulse width. They null at a frequency equal to the Nyquist bandwidth. In this case the Nyquist bandwidth from the relationship BT = 1 is 1/500ns = 2 MHz at baseband and 4 MHz at RF.

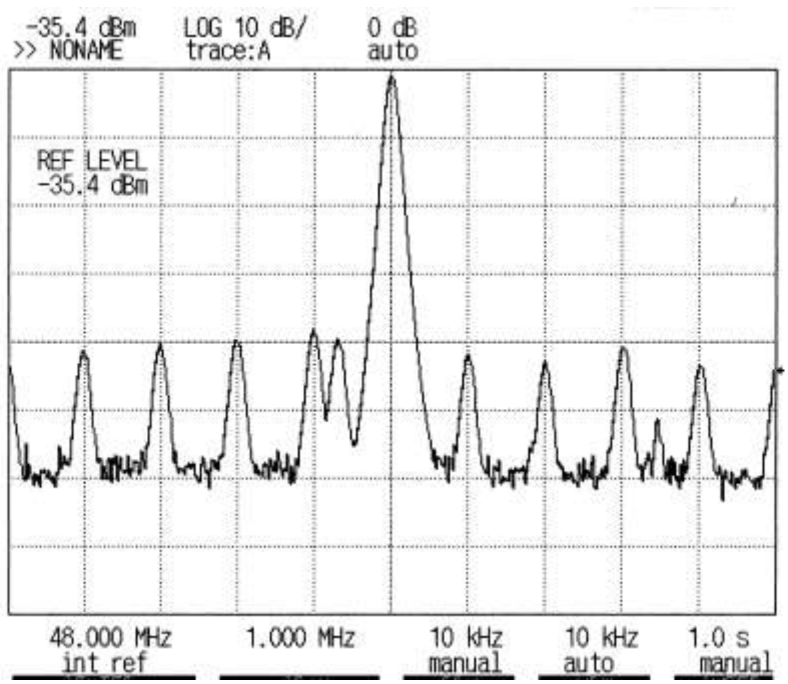

Figure 4. Post filter spectrum showing close in detail of part of the sinx/x sideband distribution,. In this example, the sidebands have been reduced 40 dB by 2 cascaded stages of zero group delay filtering. Additional stages can be added.

Assumed: Once a carrier has been modulated with contra rotating sidebands, no amplitude change remains in the carrier and only the carrier need be transmitted or received. This is verified in Figures 6 and 7.

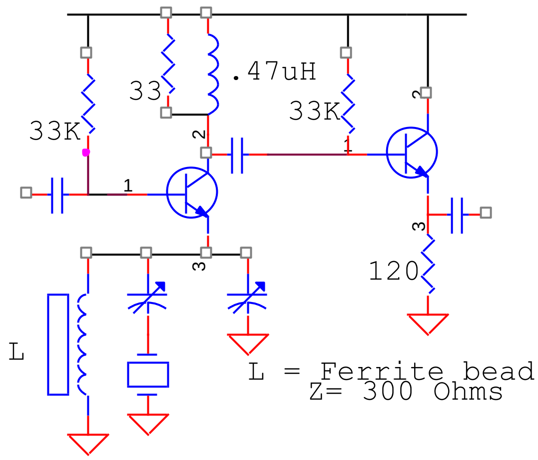

Figure 5. Ultra Narrow Band series emitter near zero group delay filter. This filter does not shape or distort the pulse waveform as Nyquist criteria filters do. A rectangular pulse _in_ is a detected rectangular pulse _out_ at the receiver. This greatly improves Radar resolution and amplitude response. Emitter follower isolation may be used between cascaded stages.

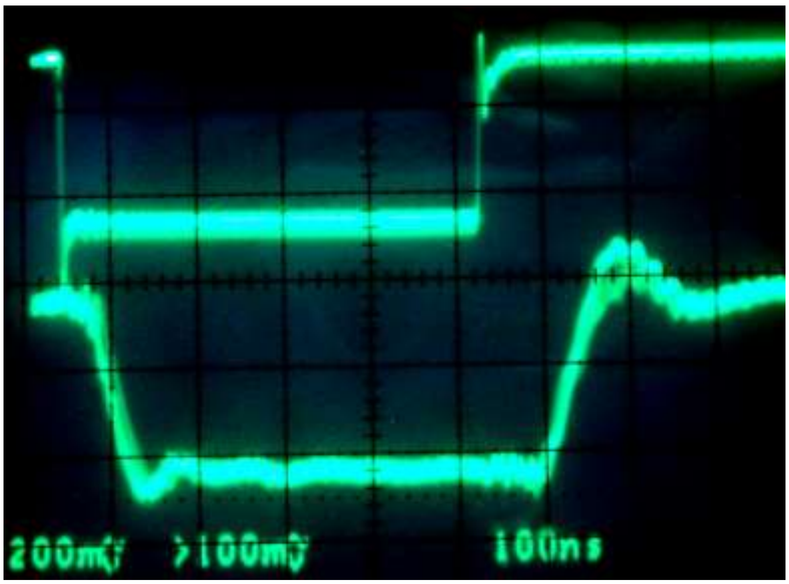

Figure 6. The baseband pulse from the test generator - above, and the detected RF pulse - below, after two stages of series emitter zero group delay filter, using a synchronous detector. The sidebands are reduced 40 dB. The pulse is 500 nanoseconds wide. The filter frequency is 48 MHz. The repetition rate ($1/T_p$) is 100 kHz. Note that the pulse shape is retained.

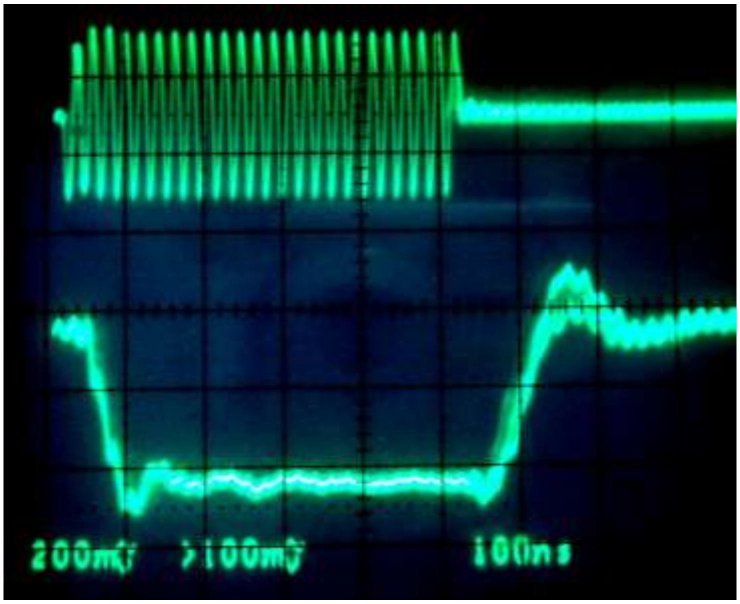

Figure 7. The same recovered pulse showing the RF cycles at the filter input instead of the baseband keying pulse. This shows a resolution of +- 1 RF cycle in a RADAR or similar pulse system. The range resolution is +- 3.3 meters. This resolution could not be obtained from a matched Nyquist filter having a bandwidth B = 1/T. The SNR improvement over a BT = 1 Nyquist filter is approximately 36 dB due to the bandwidth reduction. The leading edge varies + - 1 RF cycle because the baseband signal and the RF pulse start and stop are not synchronized.

The signal seen in Figure 7 is the same when detected with or without the 2 stage filter that was used, indicating there is no envelop group delay in the filter and that the sidebands are not making any contribution to the detected signal waveform after filtering.

Detection:

Any detector circuit can be used. Figures 6 and 7 were made using an NE602 Gilbert cell as a synchronous detector. Synchronous detectors are probably best for weak signals. Square law diode detectors have also been used successfully.

Mathematical Relationships:

For all AM methods:

$$I_t = I_m [1.0(\cos \omega_c t) + 0.5K (\cos \omega_c + F)t + 0.5K (\cos \omega_c - F)t] \qquad \text{Eq. 1.}$$

Where C is the carrier and F is the amplitude modulating signal This is an AM sequence for which all components are required for modulation, but not for pulse reception. The carrier is continuous for audio, but pulsed On/Off for pulse modulation. K is the modulation index, which is presumed to be 1.0 for pulse modulation. F is the Fourier transform of the modulating signal.

Equation 1 is the general equation for all AM modulation methods, including pulse modulation. Each sideband contributes 0.5K to the signal, where K is the modulation index. When the sidebands are reduced 40 dB as shown in Fig. 4, it is the equivalent of reducing K to 0.005.

The Fourier spectrum for a pulse using rectangular pulse modulation is:

$F(t) = A_{peak}\,(t/2T_p)\,[\,½ + (2/\pi)\cos\pi(t/2T_p) - (2/2\pi)\cos 2\pi(t/2T_p) + (2/3\pi)\cos 3\pi(t/2T_p)$
$-(2/4\pi)\cos 4\pi(t/2T_p) + (2/5\,\pi)\cos 5\pi(t/2T_p)$ ---]

- which nulls when nt = 1.0. The DC component can be ignored. ($1/T_p$)is the repetition rate and 't' is the pulse width. Eq. 2

This is the baseband signal equivalent to the modulating signal F in Equation 1. A difference is to be noted in that the carrier – cos ωt – is being turned on and off by F(t)

This signal results in the numerous sideband frequency spikes which are seen in Figure 3. Alternate +- frequency spikes cancel in phase so that only the difference in level between them adds to the total sideband amplitude. The total contribution of all of the sideband spikes to the total signal power is only 6 dB, as indicated by equation 1. Half the signal energy is in the carrier.

When a very narrow band negative group delay filter is used, the components of the Fourier spectrum are separable and can be used independently as in the present case where the carrier alone is used. There are UNB data methods that use a single sideband frequency alone

Note: While the spectrum analyzer shows the spectral component level rising and falling with a change in pulse width, the voltage peak as seen at the filter and detector outputs (Figs. 6, 7) does not change as pulse width is varied.

$F(t) = A_{peak}\,(t/2T_p)$ changes with $t/2T_p$, but this has no effect on carrier voltage levels, or detected output level.

Summary:

Amplitude modulation utilizing pulses is ON/OFF modulation. If the signal is ON, it is there, if it is OFF it is not there. This is equivalent to a tuning fork that is struck to start the ringing. If is critically dampened, the ringing stops when there is no further energy input. Start and stop are near instantaneous. Negative or zero group delay filters provide critical dampening. The formula $T_g = Q/IF$ applies. If T_g is zero, the Q is zero. Alternately, if Q = 0, then T_g = rise and fall time = group delay = zero. Therefore the filter is critically dampened and doesn't continue ringing with stored energy. It must be fed continuously during the pulse period and ringing stops when the pulse ends.

These measurements show that even when the sidebands are reduced to insignificance, the AM pulse is still recoverable with only a 6 dB loss. The sidebands are therefore not necessary. This is true only for AM pulses. The sideband removal and SNR improvement is applicable to any AM pulse system, such as PAM, PWM, RADAR, DME, IFF, Tacan and UWB.

The method has been used with UNB data modulation methods since 1998. Ultra Narrow Band modulation as used for data is end to end AM pulse width modulation with different phases on the pulsed carriers to represent ones and zeros.

It is absolutely essential that the filters used to remove the sidebands have zero envelop group delay. Ordinary filters that match the Nyquist criteria (BT = 1) have group delay, which causes an RC like rise time, shaping the pulse, and the pulse would never rise rapidly enough to be detected with a 500 Hz IF filter bandwidth. Figure 5 is an example of a near zero group delay filter where the rise time is one IF cycle and the Nyquist bandwidth B, from BT = 1, is equal to the intermediate frequency. The method does not in any way violate Nyquists criteria, or Shannon's Channel Capacity equation, if the proper bandwidth is used in the equations.

The method cannot be used with audio AM, or FM/PM, but there are methods to transmit audio using the carrier only with excellent results. (Ref. 1). Only when the frequency islands created by the Fourier transform of equation 2 are present, can the carrier be used separately.

Radar systems involving moving targets will have a Doppler frequency shift effect that can cause the signal to be outside the very narrow bandpass of the filter. There are circuits to correct for this in references (1) and (4).

The greatly reduced bandwidth and improved SNR will increase Radar ranges by factors of 30/1 to 100/1. They also make it possible to detect much smaller targets.

References:

(1) H.R. Walker, "Ultra Narrow Band Textbook", available for free download from www.vmsk.org. 224 pages.
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(3) August W. Rehaczek, " Principles of High Resolution RADAR", Mc Graw Hill, 1969.
(4) Donald G. Fink and Donald Christiansen, " Electronic Engineers Handbook", McGraw Hill, 1989. Chapter 25. This reference, especially Chapter 25, is highly recommended for information on Doppler and Resolution using different Nyquist criteria filters.
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McGraw Hill, 1951.
[6] US Pat. 7,424,065 H.R. Walker, "Apparatus and Method for an Ultra Narrow Band Wireless Communications Method". 9/9/2008.
[7] Google or Bing on 'Negative Group Delay'
[8] http://www.vmsk.org, File on NGD.
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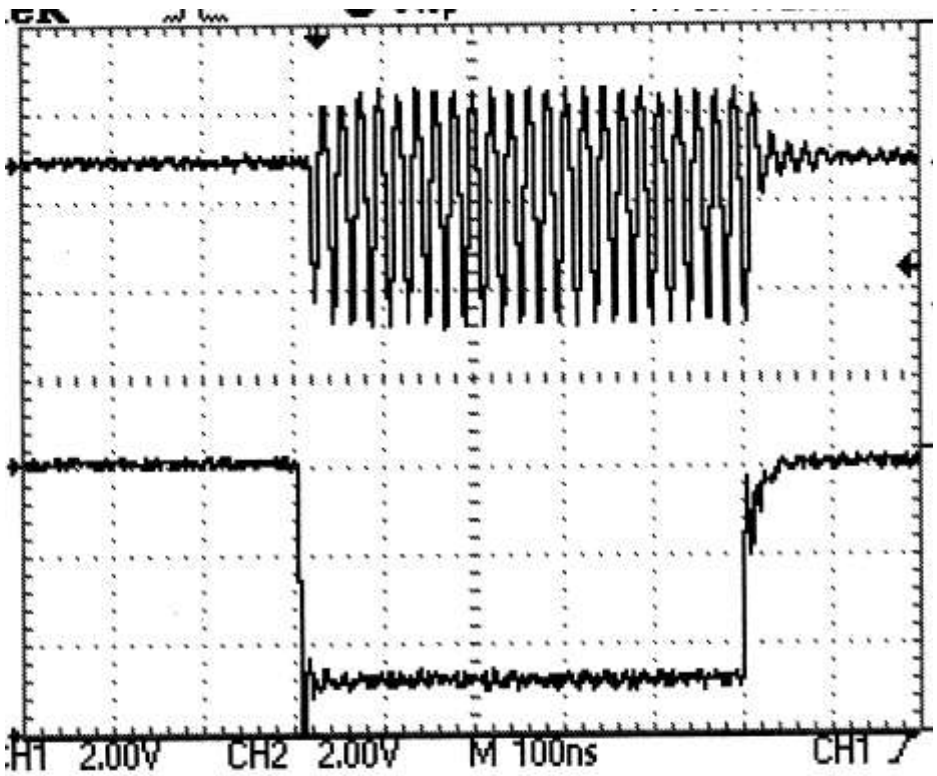

Figure 6.

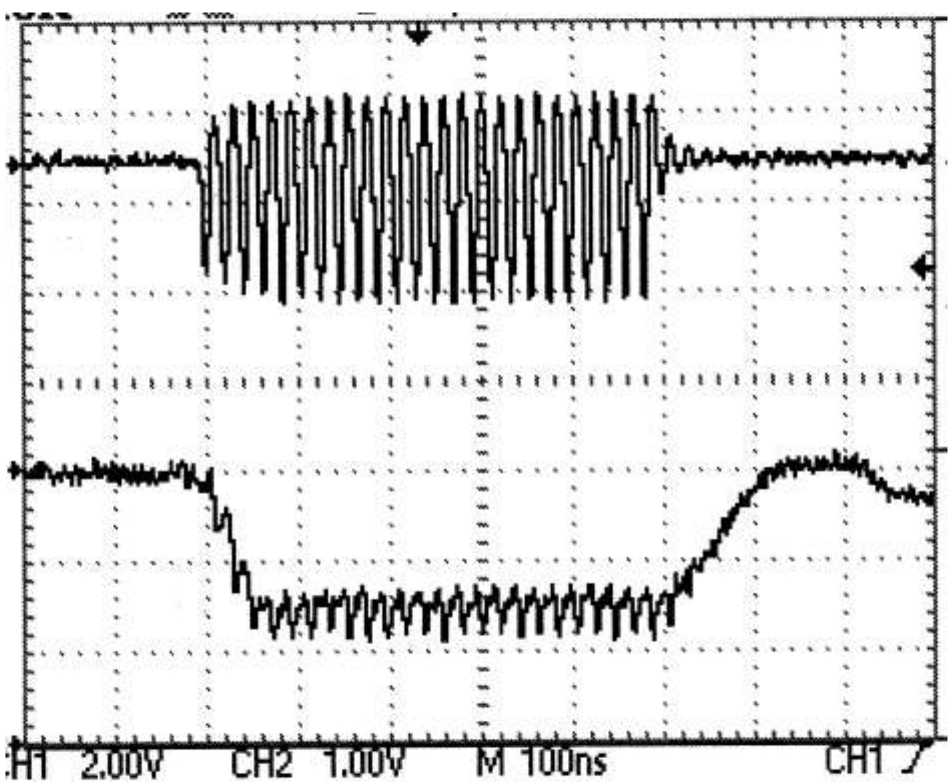

Figure 7.