

3PRK Modulation Complies With FCC Requirements Measuring Mean Power Levels in 3PRK Spikes

Measurement is applicable to 3PRK and 3PSK) (6/12/08)

The FCC requires that power across various frequencies of the transmitted spectrum be measured as mean (RMS) power. For Cellular systems using F1D modulation, the critical bandwidth is 30 kHz. The setup shown below utilizes the Analog Devices AD8306 chip to obtain the measured RMS output from the RSSI. Since the chip is not calibrated directly, a substitution method is used. For a sine wave, the correction factor is 0 dB. Therefore, if a reading is made as peak voltage level (a) for pulses, a sine wave can be substituted to obtain the same voltage level. The RMS power level for the pulses is then the measured level relative to the sine wave. Since the desired FCC reading is the ratio of the peak un-modulated voltage to the RMS voltage in the pulses, the method is accurate.

Ordinary crystal filters cannot be used to measure narrow pulse levels. For this reason, a 3 kHz wide filter having a very low (near zero) group delay was used. If the signal consisted of a bandwidth spreading signal, the reaction would be the same as for noise and the 30 kHz level would be the present reading plus 10 dB. Since the $\sin x/x$ signal consists only of single frequencies, the peak value through this filter is the same as it would be if the filter had 30 kHz of bandwidth. (See Fig. 4). This can be seen on the peak reading spectrum analyzer where the peak readings do not change with bandwidth settings. This bandwidth response is adequate for a data rate of 266 kb/s, where the $\sin x/x$ spikes are 266 kHz apart and the grass that accompanies 3PRK modulation lies in between the spikes. The RMS measurement can be made at the $\sin x/x$ peaks and at the region in between. The group delay of the reference 30 kHz crystal is 26 microseconds. For 3 PRK modulation the spectrum analyzer can be relied upon to give good relative ratio measurements for the $\sin x/x$ peaks. This is not true for the region between the spikes where the peak level varies with the modulation pattern. The peaks in this region do not give a true representation of the RMS value, hence a a different RMS measuring method is required. Although this region between spikes is considered to be 'noise' and can be filtered off. It does have the similar peak to RMS relationship as Gaussian noise.



Fig. 1. Substitution

For these tests, the carrier is at 24.000 MHz. The narrow band filter is at 23.468 MHz, or two lobes away from the carrier. The response curve for one section of this filter is shown below.

For confirmation purposes, an Analog Devices AD8361 True RMS chip was used with calibrated external gain amplifier. The same confirmation test was made with an HP3403C True RMS Meter after the filter. These confirmation tests merely confirm that

the AD8306 RSSI output is an RMS output with the wide dynamic range required to cover more than 60 dB in level changes as claimed in the manufacturer's literature. The dynamic range can be extended by using pre-amps.

3PRK modulation consists of a main lobe at the carrier frequency, containing more than 99% of the radiated power. The RMS level is 3 dB below the peak spectrum analyzer reading. This is accompanied by a multitude of lesser spectral spikes, which spread out to either side for a considerable distance. It is these lesser $\sin x/x$ spikes and the region between them that concerns the FCC.

The modulation is by means of very narrow pulse equivalents using pulse position modulation to separate the ones and zeros. The time between the narrow pulses is filled with the carrier frequency - undistorted. The narrow pulse is 1 cycle wide. The carrier contains approximately 100 cycles per bit. Examination of the waveform shows a 180 degree phase reversal for one cycle, so the method is G1D under FCC Regs. It can also be considered a "missing pulse" method where there are 99 pulses with 1 pulse missing. The XOR gate used as a detector will respond to either version or concept.

The minor pulses spread over a wide frequency range have a peak level relative to the main peak according to the relationship t/T , or $1/100 = -40$ dBV. The time on, vs the time off, is also $1/100$, so the average voltage in each $\sin x/x$ frequency bin is 40 dB below the peak voltage of the carrier. The mean power (RMS) in each frequency bin is double this, or -80 dB relative to the main lobe.

In addition, if the time period of the missing pulse is $1/100$ bit period, the 30 kHz filter cannot pass it due to the filter group delay. The pulse width is 30-40 nanoseconds. A special near zero group delay mono-crystal filter is required to receive the signal, or to measure the RMS values.

With a 24.000 MHz carrier and a 266 kb/s data rate, the bit period is 90 carrier cycles. The missing pulse time is $(1/90)$ bit period, or .042 microseconds. A pulse .042 microseconds wide requires a filter 22 MHz wide to pass it. A 30 kHz filter will pass only $30/22,000 = .00136$ of the peak pulse for a filter loss of 56 dB. The mono-crystal filter is an exception.

This means the numerous $\sin x/x$ spikes are not expected to pass through the filter and give a meaningful RMS power reading in a 30 kHz bandwidth. The total mean power loss is expected to be $(1/80)(1/80)(30/22,000) = 132$ dB. This is below the measurement range of the test setup.

To provide an accurate reference relative to the main lobe, which has close to 99% of the un-modulated power, a sine wave from a generator having a peak level equal to the strongest of the $\sin x/x$ pulses is substituted for the $\sin x/x$ pulses. The RMS levels were measured and recorded.

For test purposes, the main lobe was notched filtered to the lowest possible value, while the sinx/x pulses remained unchanged. This prevents most of the carrier from bleeding through the filter.

If the sinx/x pulses show a measured mean (RMS) level -60 dB below the main carrier, the 3PRK system is believed to comply with FCC regs. for G1D modulation using Cellular channels. 3PRK is "Pulse Position Phase reversal Keying", with a phase change of 180 degrees for 1 cycle, thus it qualifies as phase modulation, or G1D, or F1D under the rules..

There is a lower noise floor between the pulses, which can be seen in the spectrum analyzer plots below. This is the true limitation in meeting FCC specs., not the sinx/x spikes. If the sinx/x spikes are reduced to insignificance, the noise floor, or "grass" is the determining factor. If this grass appears at -60 dB relative to the main lobe, then removing the sinx/x spikes entirely will not allow the interference level to go below -60 dB. This 'grass' level behaves like white noise, that is, the level varies with bandwidth

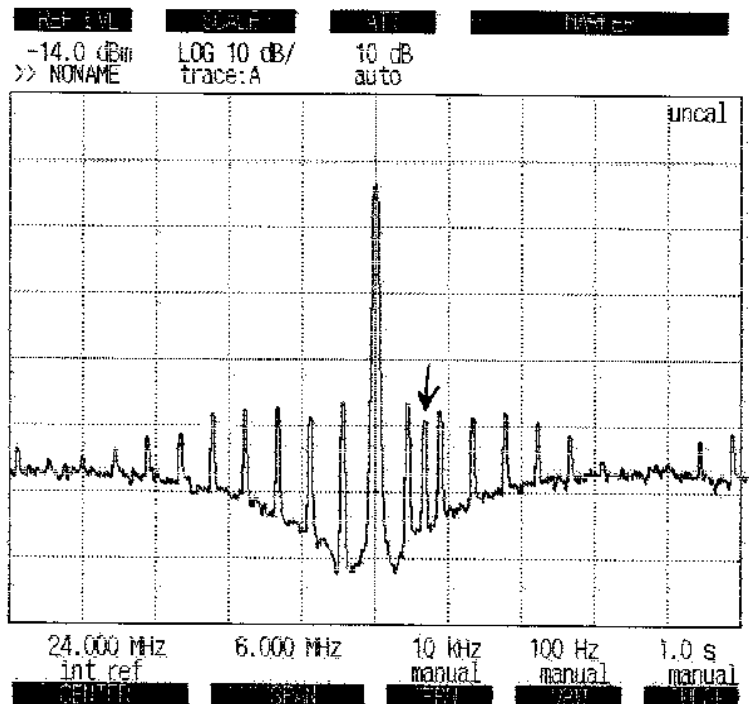
A narrow bandpass filter of special design, such as that used for these tests, can reduce the grass level by 10 - 20 dB per stage without significant detected signal level loss based on the 180 degree phase shift.

Variations: Using calibrated gain stages ahead of a True RMS meter such as the HP3403C, the filter output can be measured directly without the AD 8306.

The 3PRK system also functions without pulses indicating a digital zero. Only a pulse indicating a digital one need be transmitted. This reduces the averaged peak power and reduces the 'grass'. Fig 6 below shows the spectrum with no zero pulses. This spectrum can be used with the substitute CW reference to measure the RMS level of the sinx/x pulses without interference from the grass floor.

Using a notch filter to remove the carrier (main lobe) will extend the measurement floor of the sinx/x pulses to a level lower than -60 dB.

Figure 2 shows the spectrum with both ones and zeros present. The arrow indicates the placement of the movable CW reference signal. Both sinx/x spikes and grass are visible. A CW reference signal is seen below the arrow.



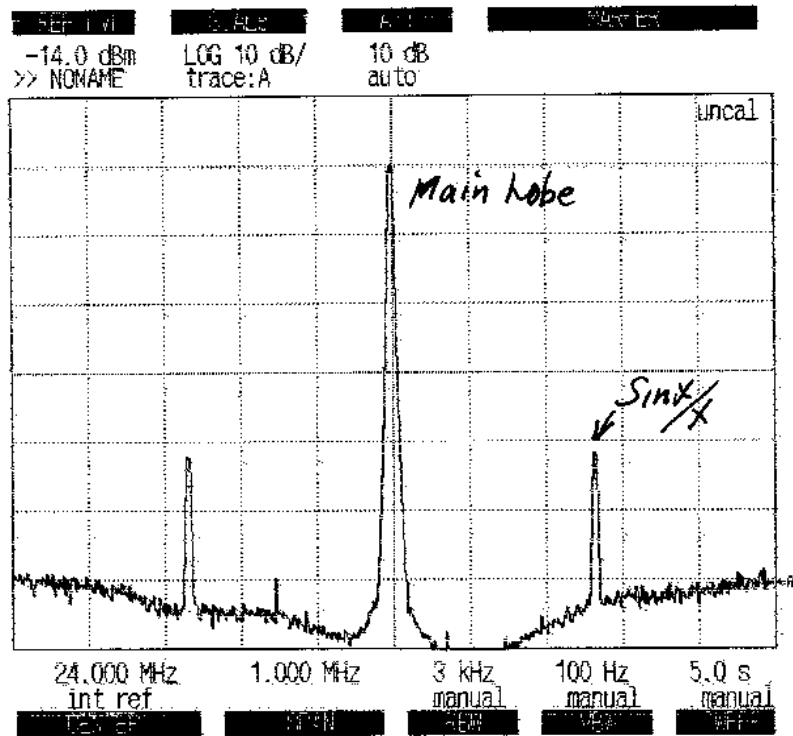


Figure 3 shows the inner region of the spectrum. The closest sinx/x spikes are 40 dB peak below the main lobe (un-modulated carrier). The RMS level is much lower.

Figure 4 shows the inner region above using a 30 kHz filter BW. Note that changing the filter BW did not change the peak levels.

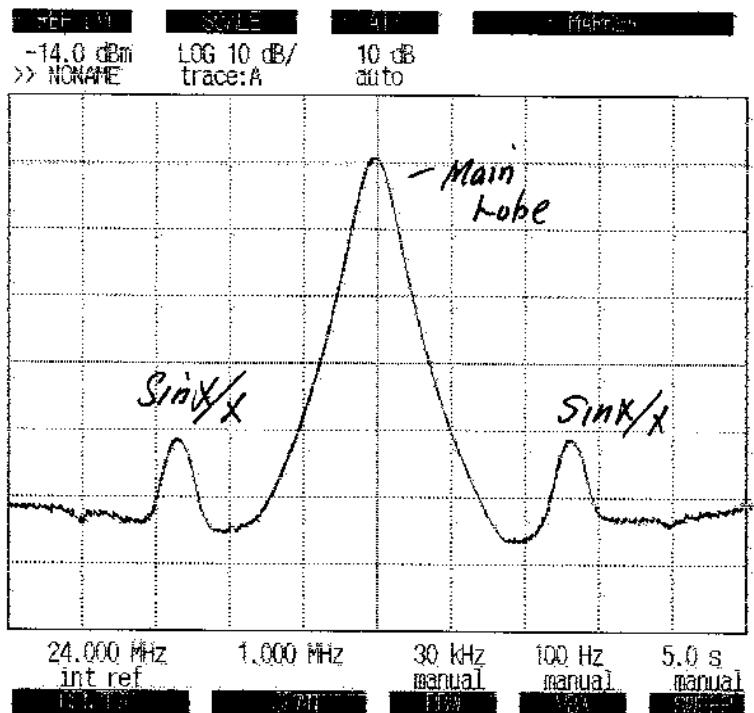


Fig. 5 shows the inner region with the movable sine reference inserted at the same level as the nearest sinx/x pulses. The True RMS meter indicates the mean power level for the sinx/x spike, which must be at least 20 dB below the peak level shown for the sinx/x spike and 60 dB below the main carrier.

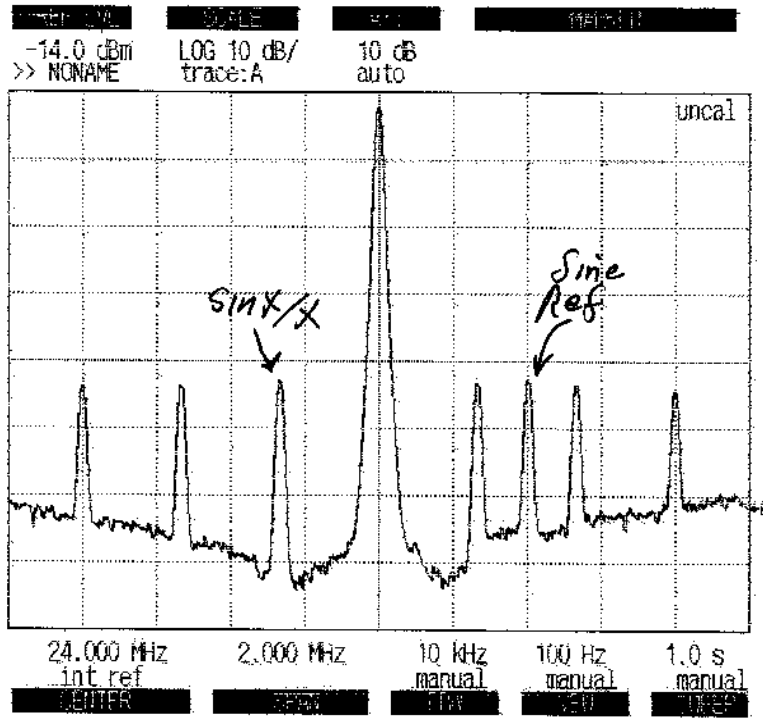
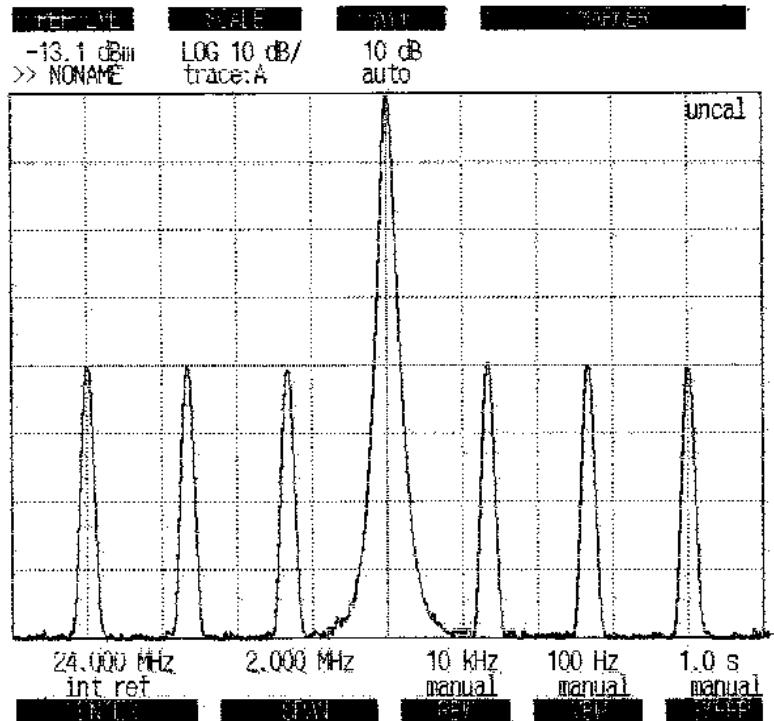


Figure 6 shows the spectrum of a 'ones only' 3PRK signal. There is no 'grass' between the sinx/x spikes, so the sinx/x spikes are the determining factor in meeting FCC regs.



The spectrum analyzer shows peak voltage values. The mean (RMS) level of the spikes is at or below the lowest horizontal line (80 dB down). This is calculated above to be -132 dB below the center peak when passed through a conventional 30 kHz filter.

FCC Regulations:

3PRK (Pulse Position Phase Reversal Keying) is 180 degree phase modulation. This is comes under F1D or G1D in the regulations for Cellular use.

Sect 22.917 (d)

(d) F1D *emission mask*. For F1D emissions, the MEAN power of emissions must be attenuated below the MEAN power of the unmodulated carrier (P) as follows:

- (1) On any frequency removed from the carrier frequency by more than 20 kHz but not more than 45 kHz: at least 26 dB.
- (2) On any frequency removed from the carrier frequency by more than 45 kHz but not more than 90 kHz: at least 45 dB.
- (3) On any frequency removed from the carrier frequency by more than 90 kHz, up to the first multiple of the carrier frequency:

At least 60 dB or $43 + \text{Log } P$ dB, whichever is the lesser.

(e) *Out of band emissions*: The MEAN power of emissions must be attenuated below the MEAN power of the unmodulated carrier (P) on any frequency more than twice the fundamental frequency by:
at least $43 + \text{Log } P$ dB.

A part of this section requires measurement with a 30 kHz filter bandwidth. Other portions of the spectrum are to use 300 Hz.

Comment: All practical systems tried have the mean power of the sinc/x spikes below -70 dB relative to the main lobe without narrow band filtering at the transmitter.

Figure 7.

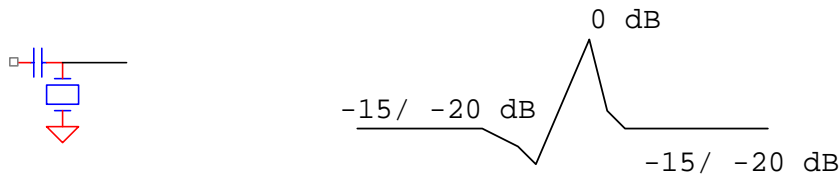
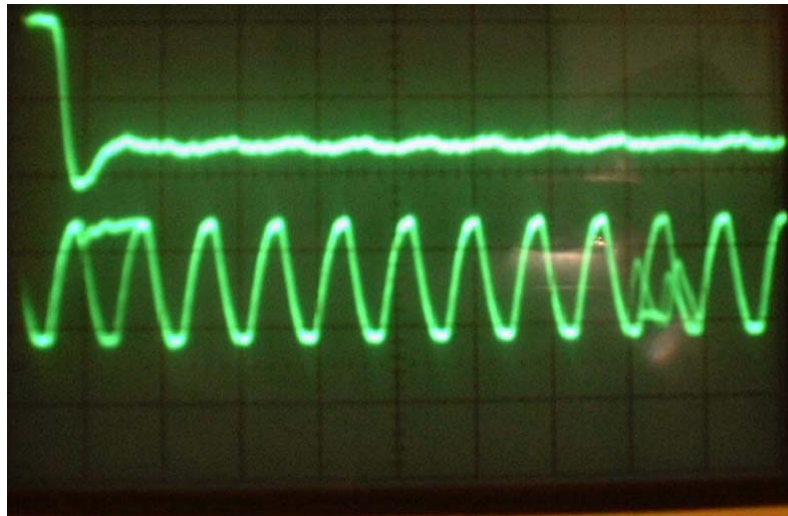
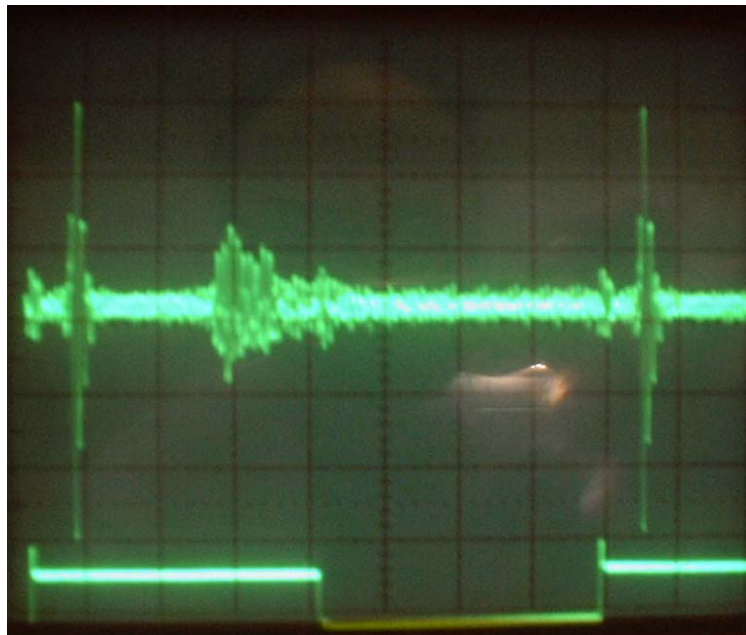


Figure 7 shows the shunt filter used to pass the narrow pulses. At frequencies above or below the parallel resonant frequency of the crystal, the crystal presents a shunt load to the input. The small input capacitor (typically 10 pf) acts as a voltage divider with X_c as one half and X_{crystal} as the other half. A high input impedance amplifier is used at the output.

The bandpass is typically 1-2 kHz at the 3 dB points and the shoulders are approximately at -17 dB below the peak response per stage. Stages can be cascaded.



The unfiltered output of the modulator main lobe is shown above. The mono-crystal filter must preserve this waveform. A digital one is seen at the left, where one cycle is robbed from the 90 cycles in the bit period. A digital zero is at the right. There is an overlay that shows both the digital one and the zero in the right and left traces. Robbing the carrier of this single cycle, causes the pulses that are seen as a sinc/x envelop. Each of the sinc/x pulses in this envelop has an RMS level less than -60 dB below the main lobe. No further filtering of the transmitted signal is required to meet FCC regulations. Some wideband filtering is proposed to further reduce the spread.



The output of the ultra narrow band filter, tuned to a minor lobe, as seen on the oscilloscope, **shows primarily the pulses lasting 1-2 IF cycles**. There should be no signal in between. The in between signal is from poor test set up construction. Note also that the filter has a decay time of about 3-4 cycles, which detracts from the RMS level measured. If the filter had a normal group delay, (for example, 26 microseconds for a 30kHz filter), it would tend to fill in and the reading would be

the same as for a peak reading spectrum analyzer. For this reason it is necessary to use a filter with almost zero group delay- both to measure the pulse RMS and to detect the signal at the carrier with the missing pulse. Ordinary crystal filters have too much group delay to be used. They will not see the missing cycle.

Mean Power Measurement of sinc/x lobes in 3 PRK

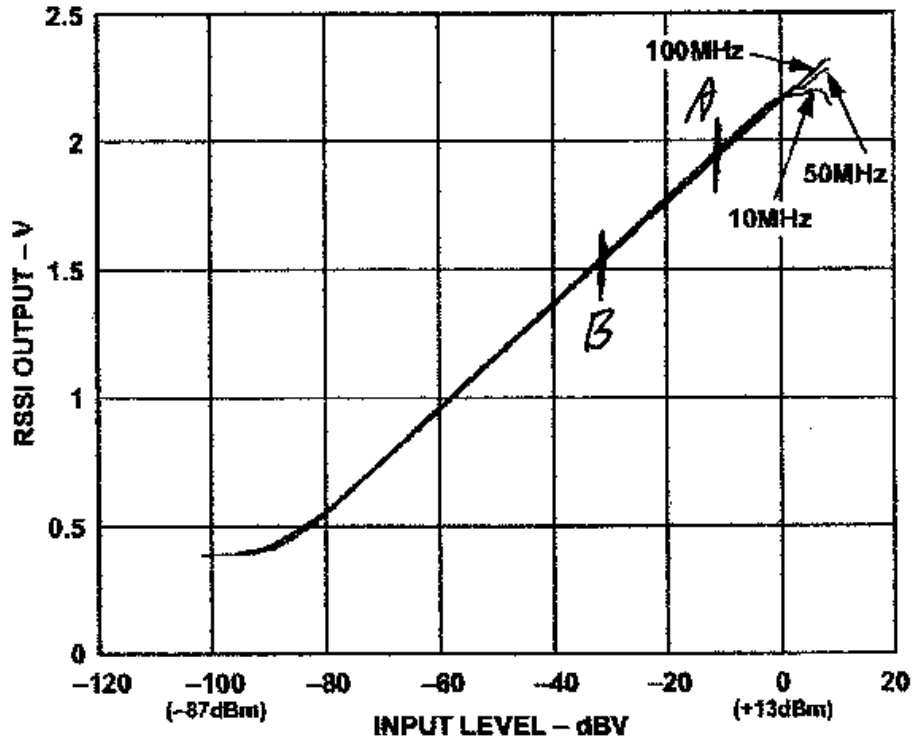


Figure 8. RSSI Output vs. Input Level, at $T_A = +25^\circ\text{C}$, for Frequencies of 10 MHz, 50 MHz and 100 MHz

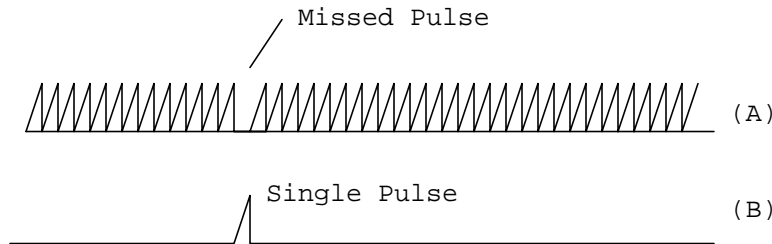
The RMS voltage measured from the AD8306 Log Amplifier with RMS output shows the RMS voltage for the spike output of the filter on one of the sinc/x lobes at 23.468 MHz. The main lobe at 24.000 MHz has been partially suppressed to prevent overload of the sidelobe in the filter. The sidelobe is - 40 dB below the carrier on the peak reading spectrum analyzer. See Figures 3,4,5,6 above.

Point B is for the measured RMS value. Point A is the reading when a CW signal is inserted having the same peak to peak value. The meter readings are 1.94 Volts for the CW signal and 1.512 Volts for the pulses. The difference is 428 mv. The AD8603 has a slope equal to 20 mv/dB. The measured difference is 21.4 dB. This represents $40 + 21.4 = - 61.4$ dB RMS below the un-modulated carrier.

Poor shielding and layout of the test boards, plus less than optimum filter shoulders, causes some bleed through of the main carrier and other board noises, which causes the readings to be somewhat poorer than calculated. The readings nevertheless indicate the method complies with the FCC regulations for out of band radiation with no transmitter

filtering. This is evident from the oscilloscope photo taken at the filter output. There should be no signal in the space between the pulses. Even when there are no pulses (no modulation), there is some signal bleed through which is readable 532 kHz away from the un-modulated carrier. **This results in a meter reading floor, which was observed to be at a meter reading of 1.512 volts. The True RMS value of the pulses is much lower than measured.**

Calculating Mean Power Levels:



Assume an RF frequency with 101 cycles per bit period. The main power spike has 100 cycles and the single pulse 1 cycle. The ratio is 100/1 in time difference.

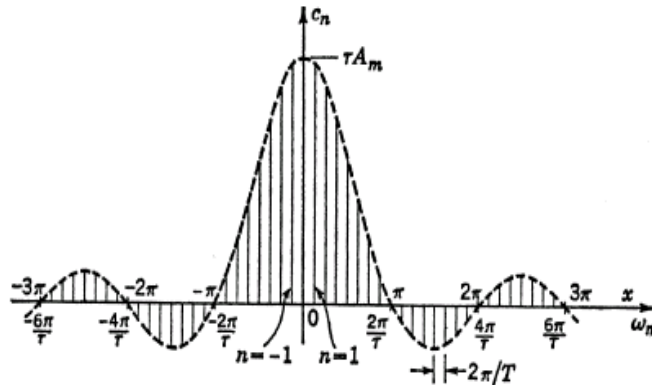
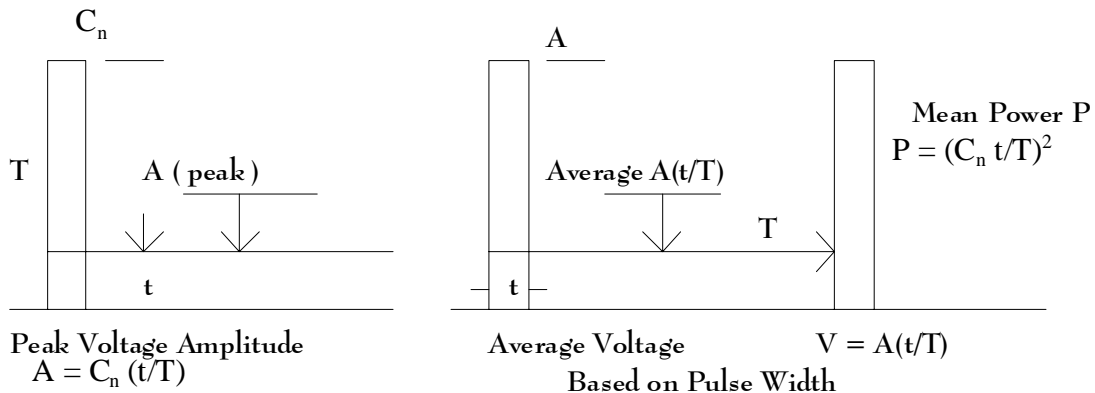


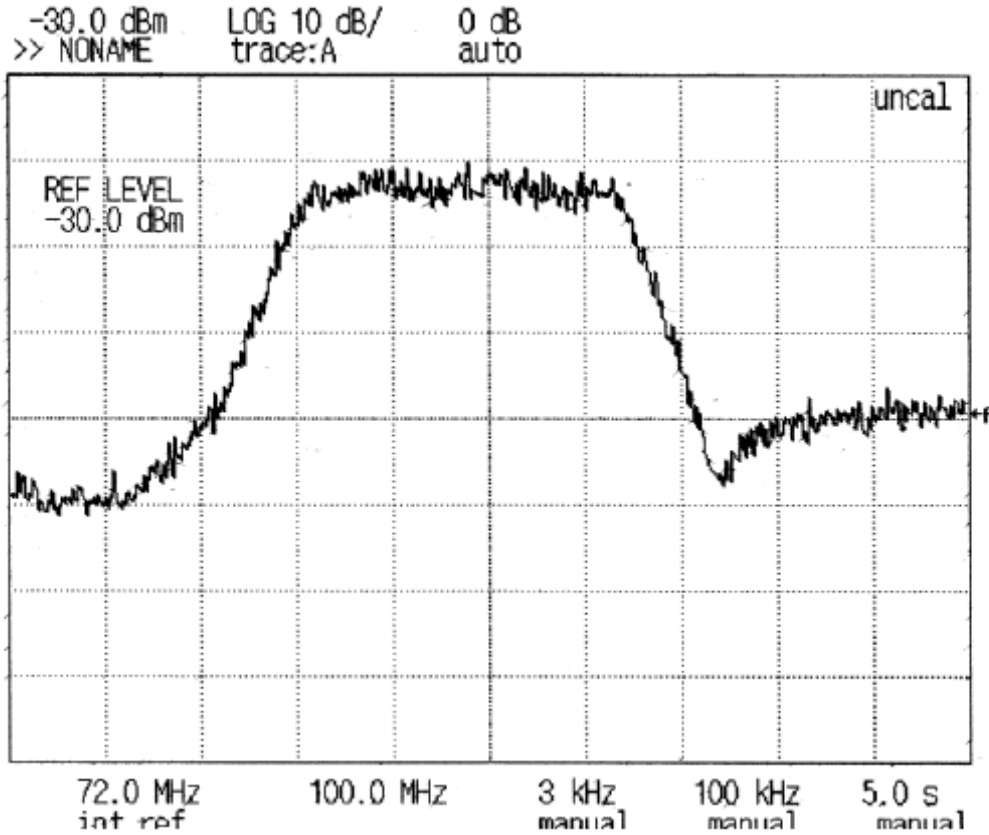
FIG. 2-8. Frequency spectrum, rectangular pulses ($\tau \ll T$).



This is classical pulse analysis. There will be minor spikes spread as shown above over a wide spectral range. The peak level of these spikes is calculated below.

The minor pulses will have a peak value of 1/100 the peak of the major pulse (-40 dB). But they will have only 1/100 of that level as an average voltage. The mean power is at -80 dB.

Measurements show the strongest peaks are at $-20\text{Log}_{10}(T/t)\text{dB}$. The RMS value is $-40\text{Log}_{10}(T/t)\text{dB}$. Since ones only are transmitted, there is an additional 6 dB reduction in A_{av} . $\text{RMS} = [-40\text{Log}_{10}(T/t) - 12]\text{dB}$.



Noise Bandpass of the 70 MHz filter used with the 60 MHz Cable TV receiver. The Sinx/x spikes outside this bandpass are reduced 30 dB. The group delay of this filter is around 20 ns. Nominal bandpass is 70 MHz \pm 18 MHz.

Interpreting the Spectrum Analyzer;

A good quality spectrum analyzer presents accurate data when properly interpreted. The levels shown are peak leaks for a signal present 100% of the time at a single frequency. The level observed changes when the signal is not present 100% of the time and the bandwidth of the analyzer filters changes.

Assume a filter 10 kHz wide. The filter will have a rise time (envelop group delay) which calculated according to Equation 1 is 25 microseconds.

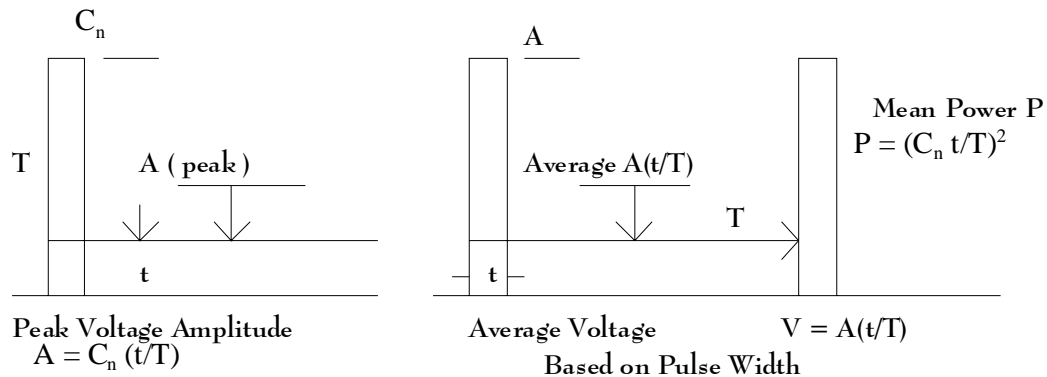
$$T_g = [\Delta\Phi / (2\pi \Delta f)]$$

$$\text{Eq. 1. Derived from } \omega t = \Phi.$$

For LC or Gaussian filters, this is:

$$T_g = [1/(4\Delta f)] \quad \text{or} \quad T_g = Q/[4IF] \quad \text{Where IF is the filter center freq.}$$

If the signal is present for 25 microseconds, the displayed level will peak at the signal peak. If the signal is there 5 microseconds, 1/5 th of the time it will rise to show a peak on the analyzer of 1/5 the actual peak. The voltage is averaged. The RMS level is twice the level displayed in dB.



The following spectrum for a 3PRK signal at 2 Mb/s using random data can be interpreted as follows. The analyzer does not show an “UNCAL” warning so the readings can be assumed to be accurate.

There are spikes at 2 MHz intervals. The inner set is at -40 dB voltage average compared to the carrier, which is on 100% of the time. The RMS value is therefor -80 dB below the carrier. There may be an additional -12 dB with random data because the modulation is only there 50% of the time. 3PRK creates a phase shift only for digital ones. With random data the ones appear only 50% of the time. The spikes therefor have an RMS level of -92dB. The low level hump referred to as ‘grass’ is below -100 dB at all times.

It will be noticed that as the filters on the analyzer are made narrower or wider, the level of the lower grass hump rises and falls proportionately. The spikes tend to stay at the same peak levels.

When the FCC rules require a 4 kHz bandwidth, the measurements can be made with 3 kHz filters and the reading multiplied by 1.25.

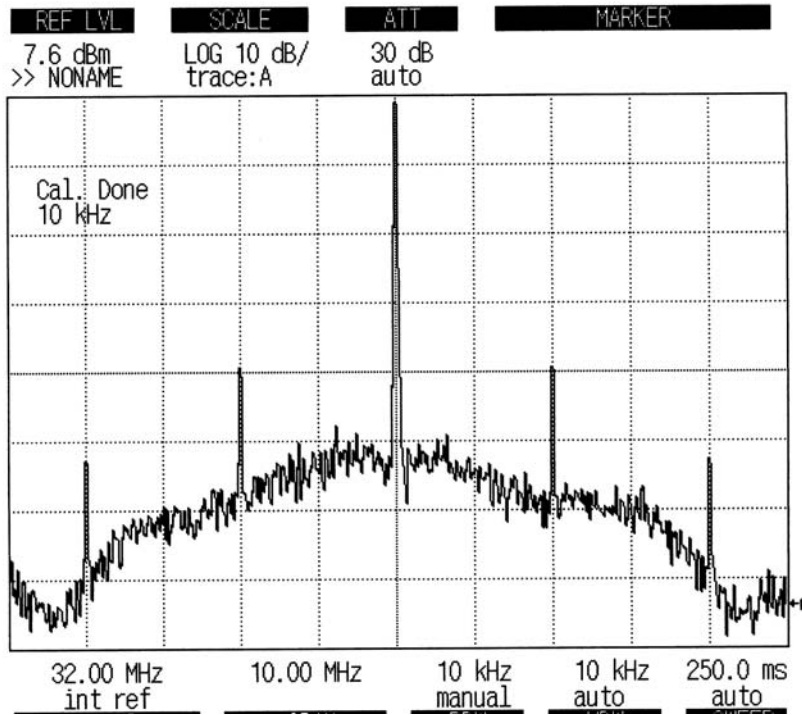


Fig. G. 3PRK --- Random Data, 50% duty cycle after one stage of Floating Bridge near zero group delay filtering