TIME SELECTIVE SPECTRUM ANALYSIS SEPARATES FREQUENCY DOMAIN CHARACTERISTICS OF: VERTICAL INTERVAL TEST SIGNALS, QUIET LINES AND EQUALIZING PULSE TO EVALUATE BANDWIDTH, NOISE AND INTERMODULATION PRODUCTS NON-INTRUSIVELY ON A CATV SYSTEM.

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ABSTRACT

Complex modulation, crowded frequency spectra, and the demand for higher signal quality require that high dynamic-range measurements be performed on operating systems without interrupting service. The problem of locating the point at which the signal has gone bad is further complicated when testing large systems containing many different functions. The ability to view at a specific instant a signal's spectrum in the presence of modulation is key to non-intrusive diagnosis of system problems.

This paper is organized in a presentation style format with main points summarized in the boxes and corresponding dialog directly to the right of the box.

Time Selective Signal Analysis Is Not New

- Radar uses timed-return signal analysis for range determination
- Fault locators use a timed return for computing distance to fault
- Some network analyzers use time- and frequency-domain reflectometry

An analogy to gating can be seen in the delayed sweep display mode in an oscilloscope, with its long time record in one trace and delay and width adjustments to intensify and then magnify a portion of the signal in a second trace. The difference is that a spectrum analyzer operates in the frequency domain. Also a stroboscope adjusted to the proper rate will stop a rotating or vibrating object.

Applications to CATV Shown in 1983

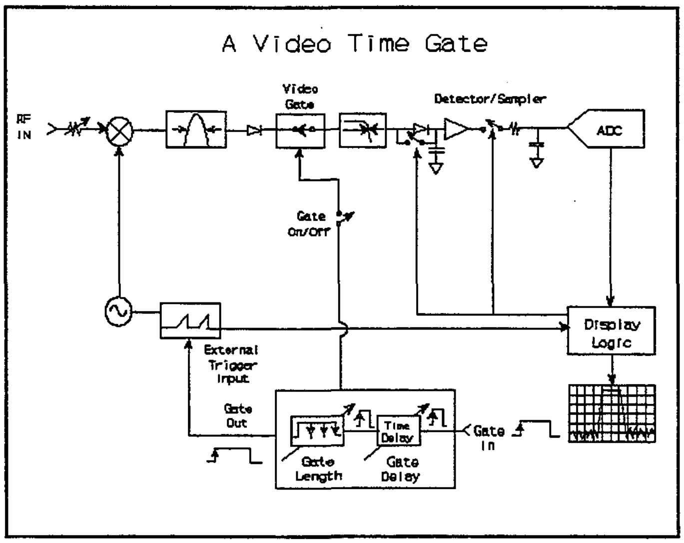
- External circuitry for timing control
- Z-axis modulation on a spectrum analyzer

John Huff has used TSSA techniques he developed since 1970 to perform CATV system proofs. However, until recently, manufacturers had not embraced these techniques. Now, TSSA proves to be the only way to view certain types of impairments.

Use of TSSA in 1992

- Digital communications -- Time division multiple access allows individual transmitter characteristics to be measured
- Disk drives -- Testing sector quality
- VCR -- Testing video-head quality

Signals having more than one contributor to the spectrum or that have a timed sequence of modulation require TSSA for determining system parameters.



gate16.cgm

Digital signal processing can be performed in several different ways. One method takes a continuous stream of data and later analyzes sections of desired data for its characteristics. This process requires a relatively large data memory, especially for low repetition-rate signals; it also requires specialized firmware processing for the characteristics desired. A second approach controls the start and stop of sweeping, allowing data to be obtained only during a desired time period. This approach is limited by how quickly the sweep can be stopped and started. A third approach takes continuous data and eliminates the undesired data, leaving the desired data for display. While this approach places the burden of control on the user to configure the analyzer for a particular measurement, it makes the fewest requirements on software to develop new measurements. This approach was taken in designing video time-gated spectrum analyzers.

Limitations on Gated Measurements

- Resolution bandwidth (RBW) settling time
- Video bandwidth (VBW) settling time
- Sweep time
- Span/RBW ratio
- Gate-timing resolution

Resolution Bandwidth

- Gate delay > 2/RBW for best accuracy
- RBW > 2/pulse modulation on time
- Proper gate delay excludes RBW skirt transient response
- RBW sets noise floor for measurement

The resolution bandwidth filters appear before the gate in the block diagram, so they are subject to all modulation entering the analyzer. The pulse rise and decay times are limited by the RBW setting. The modulation pulse width (time) may dictate the RBW setting to capture the amplitude accurately. These times are meant to cover worst-case situations of pulse modulation and production tolerances of the hardware to obtain the best accuracy. Reducing these times may be in order, depending on the specific situation. The dynamic range of the measurement is controlled by the signal level and the RBW and also is augmented by the correction algorithms used.

Video Bandwidth

- VBW > 1/gate length minimum
- Not useful for post-detector filtering

The video filters appear after the gate in the block diagram and therefore cannot be used for post-detector filtering. To prevent measured amplitude degradation, the filter must rise from zero to its final value during the gate-length time. A low-pass filter bandwidth is half that of a bandpass filter bandwidth. Therefore to prevent the system bandwidth from being degraded, the video-filter bandwidth should be even wider than the minimum for situations where RBW selection is less than optimum.

Sweep Time

- Sweep time > number of x-axis data points/signal repetition frequency
- Video averaging increases measurement-acquisition time

The x-axis of the spectrum analyzer display has a discrete number of data points. At least one burst per bucket must be captured. If not, dropouts or zero values will exist in some of the trace elements. Video averaging improves the accuracy of the noise floor measurement at the expense of measurement-acquisition time.

Span/RBW Ratio

- 40 for 0.1 dB 40 x 300 kHz RBW = 12 MHz span
- 100 for 1 dB
- 200 for 3 dB

Unfortunately, we don't know where the gate pulse will occur relative to the RBW. However, we can ensure that one-half the RBW's width for a desired amplitude error is on the order of the bucket size. Since there are 401 buckets on the x-axis, each bucket must be less than half the RBW's width for the worst-case error allowed.

Gate Resolution and Range

Gate delay

- 1 μs resolution
- 1 μs to 65.5 ms range
- ± 1 μs accuracy

Gate length

- 1 μs resolution
- 1 μs to 65.5 ms range

Gate resolution and range are determined by the clock frequency used, the length of counters following the clock, and the synchronism of the gate input in relation to the clock.

Review of Measurement and Computational Techniques

- Bandpass filter/preamplifier
- Composite distortion
- Attenuator test
- Noise-near-noise calculation
- Distortion-near-noise calculation
- Adjacent signals versus RBW

Bandpass Filter and Preamplifier

- Spectrum analyzer may add distortion and noise
- Preamplifier raises system noise 10 dB above analyzer noise
- Bandpass filter limits signals into analyzer
- Extra hardware and manual control complications

Composite Distortion

- Number of beats increases drastically with number of carriers
- Beat accumulation based on frequency spacing
- Beat level builds up relatively as 10log(number of beats)
- Measured level based on synchronism and APL of contributors
- Distortion creation mechanisms are not flat versus frequency

Beat Locations in Standard Channel Plan

General channel equation for visual carriers

- (N x 6 + 1.25) MHz for typical channel
- (M x 6 + 1.25 + 4) MHz for channels 5 and 6

General beat location

- Third order A ± B ± C & 2A ± b & 3A
- Second order A ± B & 2A

A spectrum analyzer's noise figure, and second- and third-order distortion levels may not be good enough to perform carrier-to-noise, composite-triple-beat (CTB), and composite-second-order measurements without error unless the operator exercises careful control of power input at the first mixer. External hardware is less desirable because of the likely errors introduced.

Creation of composite distortion is complex, as is its measurement. This complexity is due to the simple form (A+B-C), used for ease of analysis and basic measurement setup, coupled to the non-ideal components of diverse system configurations. Only the visual carriers are considered for beats measurement locations of CTB and CSO since they have the largest peak power, but have average power on the order of the audio carrier level. The color subcarriers, FM and digital audio and data services must also be considered for completeness. For measurement of beat products, the NCTA recommends 30 kHz RBW to include all beat products with small frequency differences in the same measurement. The NCTA also recommends 30 Hz VBW to average the peak excursions to a single value. The equation for composite triple beat, CTB = (A+B-C), yields distortion products "on visual carrier" except for channels 5 and 6, which are offset from the others. If (A+B+C) is used, not as many in-band beats are produced, but they accumulate at the high end and are 2.5 MHz above the visual carrier. If (A-B-C) is used, again not as many in-band beats are produced, but they appear 2.5 MHz below the visual carrier, which is very close to the color subcarrier of the channel below. When all carriers are considered, a computer may require days to calculate all the combinations and sum up the occurrences. Yet the process would still not be complete. If a device's distortion generation mechanism is not flat versus frequency and it changes with temperature, then these theoretical curves would be incomplete. Gating allows one to look for intermods and backtrack until the cause is found, without interrupting service.

Attenuator Test

- Carrier levels don't move with attenuator change

For distortion generated by spectrum analyzer

- Second order distortion moves at twice the attenuator step size
- Third order distortion moves at three times the attenuator step size

If no spectrum analyzer contribution

- Carrier to distortion ratios remain constant with attenuation or input level change

Carrier frequencies and levels into the first mixer determine the frequency and level of a distortion product. When the attenuator value is increased, IF gain is also increased. The signal level does not change because of this attenuator-to-IF gain coupling. For small signal levels, if the level to the mixer changes, then internally generated distortion changes at the indicated rate. For composite distortion, if the internally generated distortion is more than 10 dB below the system distortion, then the analyzer's contribution can be considered negligible.

Noise Near Noise Calculation

- Average noise power adds linearly for same RBW
- Total noise = system noise + analyzer noise
- Analyzer measures dBmV for increased dynamic range
- System noise = $10\log[10^{total/10} - 10^{analyzer/10}]$

If system noise equals analyzer noise, the total measured noise will be 3 dB higher. This equation allows accurate measurement of system noise closer than 10 dB to the analyzer's noise by backing out the analyzer's contribution.

Distortion Near Noise Calculation

- Uncorrelated distortion products appear like noise
- Beat level = $10\log[10^{\text{measured beat level}/10} - 10^{\text{measured noise level}/10}]$

This equation allows measurement of composite distortion products closer than 10 dB to the noise level. It also allows the attenuator to be set high enough to keep analyzer distortion well below system distortion. See reference 5.

Adjacent Signals

- Power of one signal affects measurement of power level of adjacent signal.
- Use narrower RBW if possible.
- Calculate effect if narrower RBW use is not possible.

The operation manuals and application notes for spectrum analyzers include use of the resolution bandwidth to resolve close and unequal signals. Signal modulation will determine what RBW must used and also whether a correction should be applied.

Gated Quiet Line

- Distortion products
- In-band noise level and slope
- Mismatch, multipath
- Local insertion contribution

Present during the vertical-retrace interval of a typical video signal are horizontal lines with no modulation (quiet lines) as well as specific vertical-interval test signals (VITS) and closed-caption or data signals. As an example, a spectrum analyzer can be set up to build a frequency domain sweep of samples acquired during a quiet line, allowing the signal to be viewed as if no other modulation were present. This setup allows one to see composite second order distortion products at +/-750 kHz and +/-1.25 MHz relative to the video carrier on any channel. In-band noise can also be measured along with noise-floor slope to determine incoming signal to noise, as well as signal to noise at any other RF location in the system.

Implementation:

Two spectrum analyzers

- Trigger receiver: spectrum analyzer with TV line trigger and fast time domain sweep
- Gated receiver: spectrum analyzer with video time gate

Tuner/demodulator and one spectrum analyzer

- CATV demodulator with composite video output
- Gated receiver: spectrum analyzer with video time gate and TV line trigger with external baseband composite video input

One approach to perform these gated measurements uses two spectrum analyzers. One spectrum analyzer with AM/FM demod/TV synch trigger and fast time-domain sweep is used as the demod and trigger source. A second spectrum analyzer with video time gate is used to perform the gated frequency-domain measurements. A second approach uses a CATV demodulator with composite baseband video output and an spectrum analyzer with video time gate and TV trigger with a special composite baseband video input. TV trigger out then is connected to gate in. An oscilloscope can aid in viewing the gate setup in relation to the horizontal line: Channel 1, connect aux video out from trigger source analyzer; channel 2, connect gate out from gated analyzer; external trigger or channel 3, connect TV trigger out of trigger-source analyzer.

Gated Trigger Source Setup

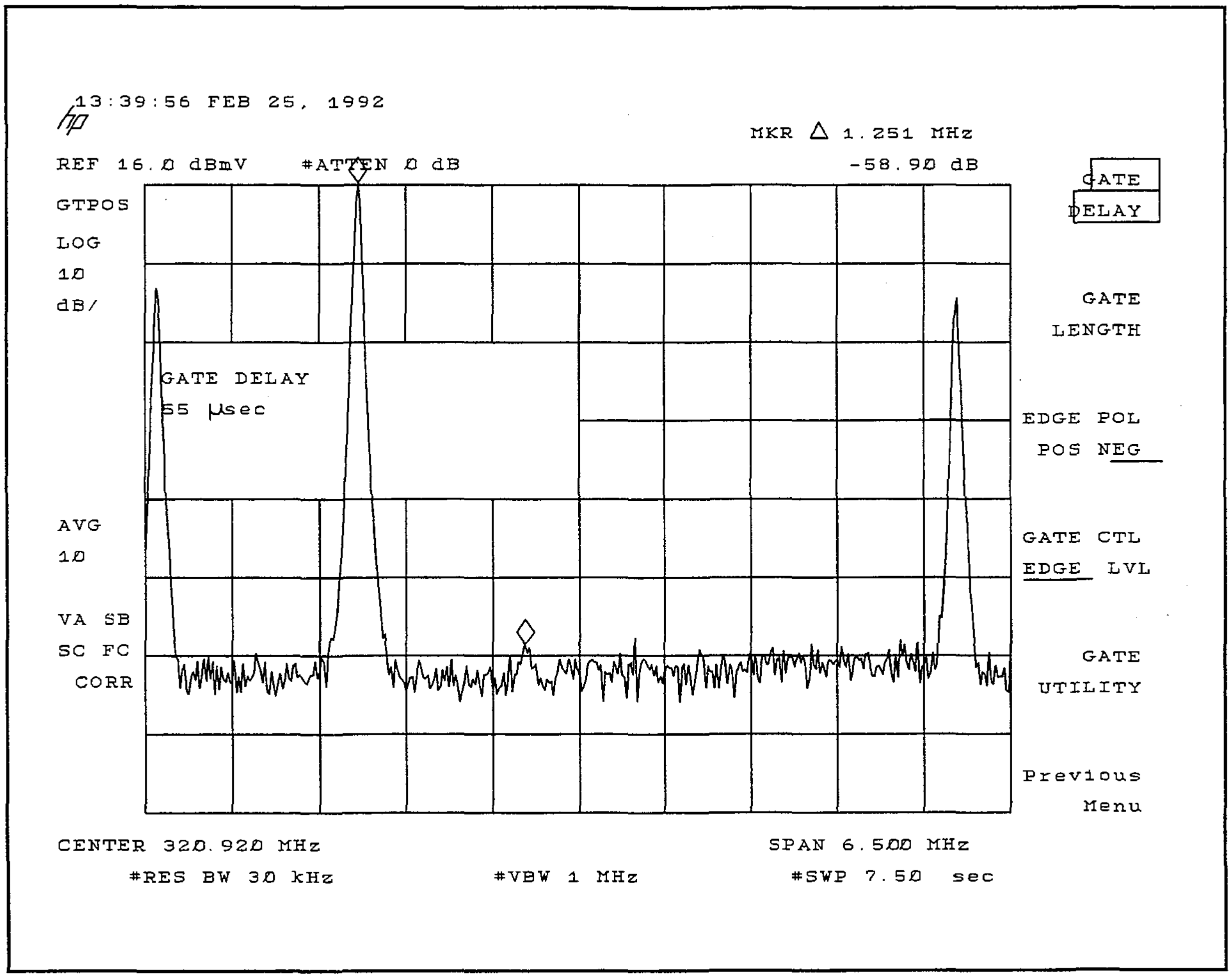
- Visual carrier frequency
- TV line number
- Field identification

For the two analyzer approach, the trigger source set-up is as follows: Set center frequency to desired visual carrier frequency of channel to be tested (55.25 MHz for channel 2). Then push TRIG hard key in control section, and then push TV TRIG softkey, which automatically sets the analyzer to 0 Hz span, 1 MHz RBW, 100 μs sweep time, linear detector, sample mode and appropriate reference level. If signal level is low, then manual selection of 0 dB attenuator may be appropriate to get stable triggering. Set the analyzer to trigger on a quiet line, which will be between lines 10 and 20 depending on test signals present and closed caption or data being transmitted during the vertical retrace interval. To reduce sweep time of the second (gated) analyzer, look in both odd and even fields for quiet time (0 IRE level), and then select TV TRIG, vertical interval (VERT INT).

Gated Analyzer Setup

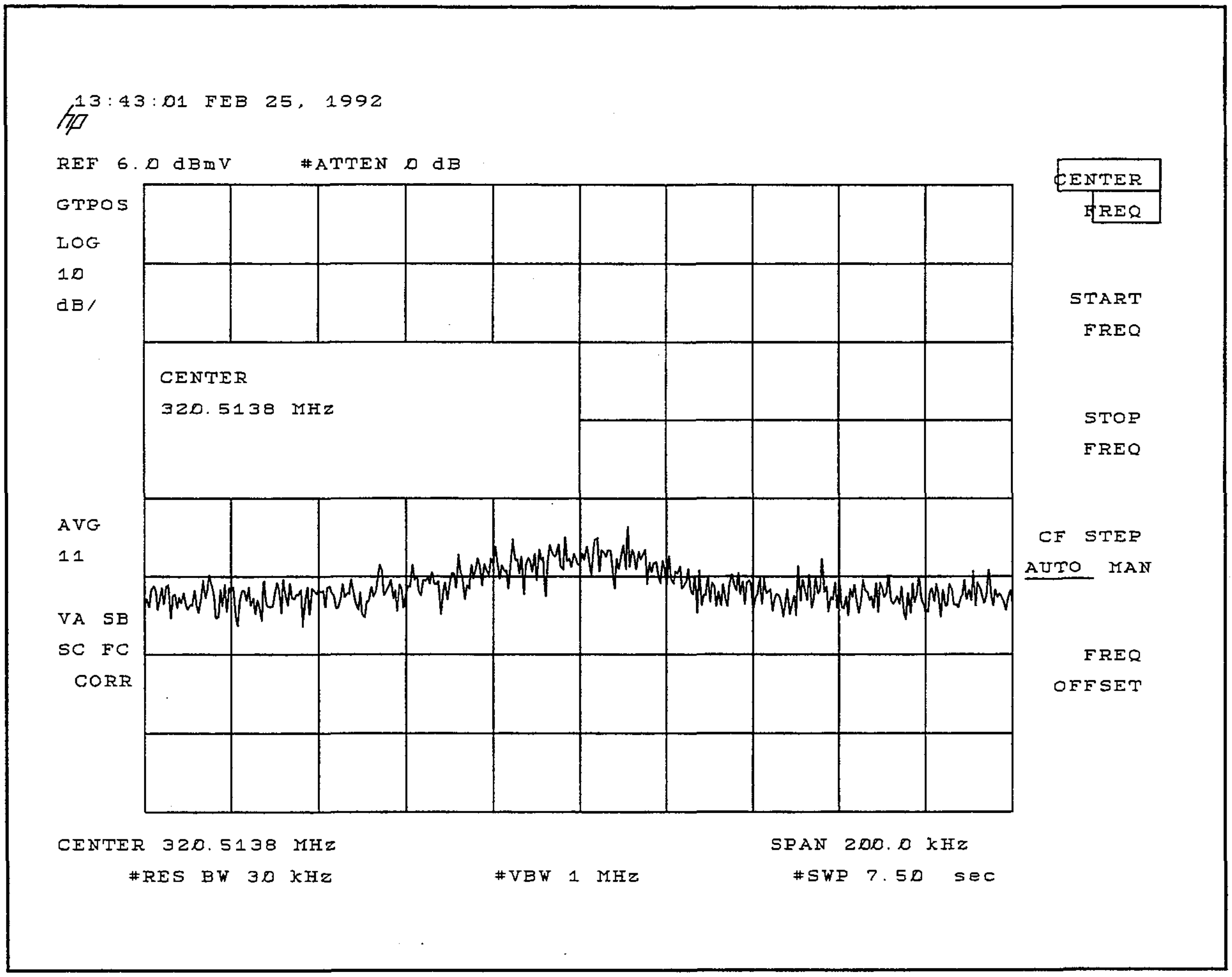
- RBW
- VBW
- Sweep time
- Gate delay
- Gate length
- Negative edge

The gated analyzer is set up as follows: Connect TV trigger output from trigger-source analyzer to gate in on the gated analyzer. Set span to 6 MHz, RBW to 30 kHz, and VBW to 3 MHz. Set center frequency to visual carrier frequency plus span/2. Set sweep time to 7.5 sec. Gate setup: set gate delay to 54 μs and gate width to 1 μs, and set for negative edge operation so reference edge for gate delay is trailing edge of sync. Turn gate ON, video average set to 10.



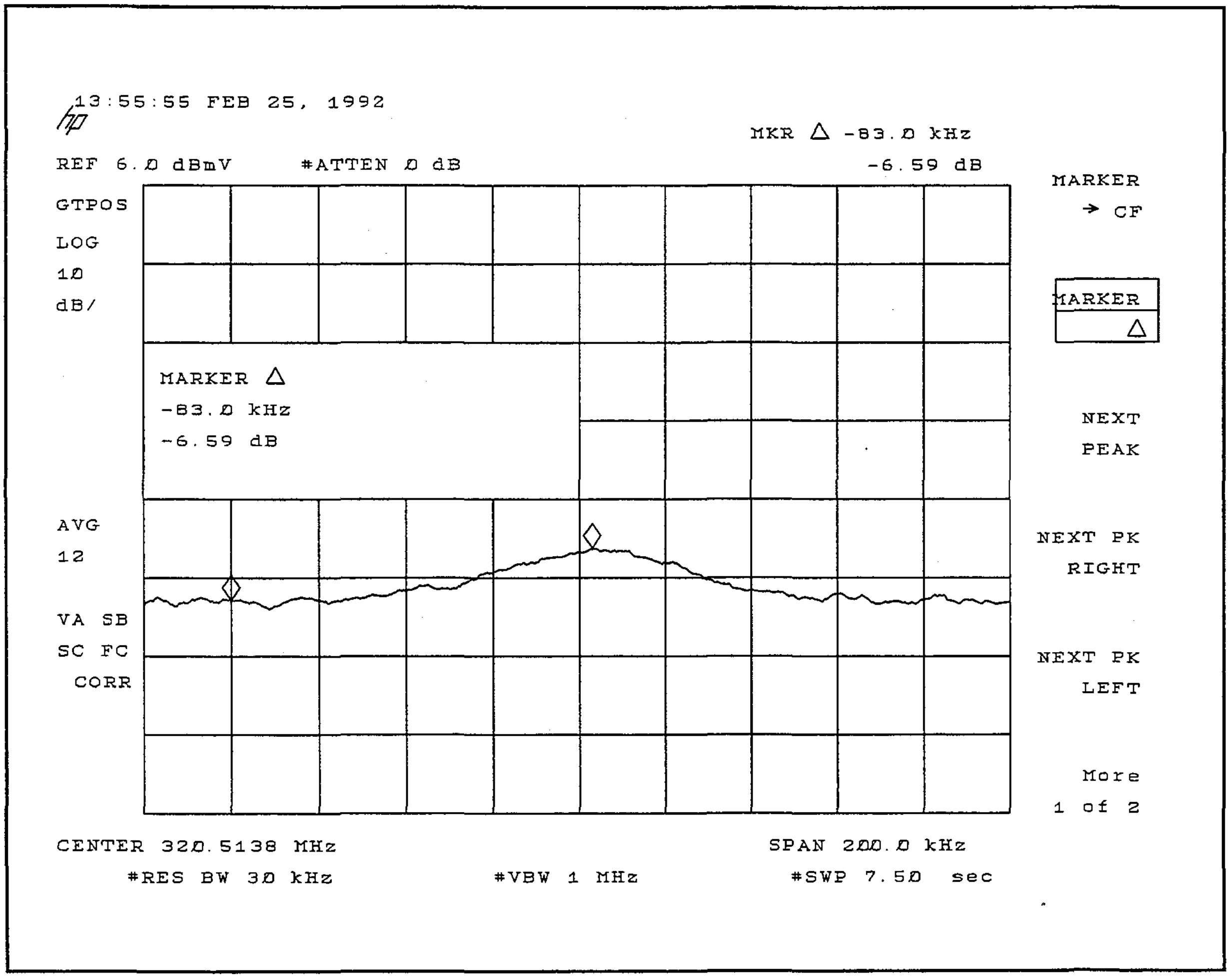
quiet1.hpg

Gated quiet line of channel 39 shows a frequency-domain representation of 0 IRE carrier level to average noise and average intermods. The accuracy of the carrier level is questionable, since the span to RBW ratio is greater than 200. The display does provide a quick look at the whole channel. To properly average noise, the carrier amplitude may have to be set above the top of the screen. If the averaged noise is not above the 60 dB graticule line, then push amplitude and set the reference level to make this so. This allows proper averaging of negative as well as positive peaks. You may have to select attenuator 0 dB if the signal level is low or a large dynamic range is needed. An attenuator test may need to be performed to check that the analyzer is not the cause of distortion. A noise-near-noise calculation will be needed if system noise is less than 10 dB above the analyzer noise. Attenuator should be set to manual, so that reference level changes don't change the attenuator value and the mixer's distortion performance. See the reference 5 for graphs of C/N, CTB or CSO for default attenuator starting point versus carrier level.



quiet2.hpg

Zoom-in on the +1.25 MHz CSO product. The accuracy of this noise measurement is based in part on the number of sweeps being video averaged, so a trade-off exists between time to acquire the data and the accuracy of the data. The gated positive peak detector is being used, but the gating process uses a 1 μs gate length so it effectively samples the 30 kHz RBW as long as the sweep time is set for one sample per bucket. Logged noise reads high by 2.5 dB, so subtracting 2.5 dB from the absolute noise level is in order. RBW reads low by 0.5 dB when compared to impulse BW, so add 0.5 dB correction. To refer the noise level to another RBW, use 10log(RBW new/RBW old). For noise measured in a 30 kHz RBW and referred to a 4 MHz RBW, the correction factor would be +21.25 dB. Noise-near-noise correction will also be needed.



quiet3.hpg

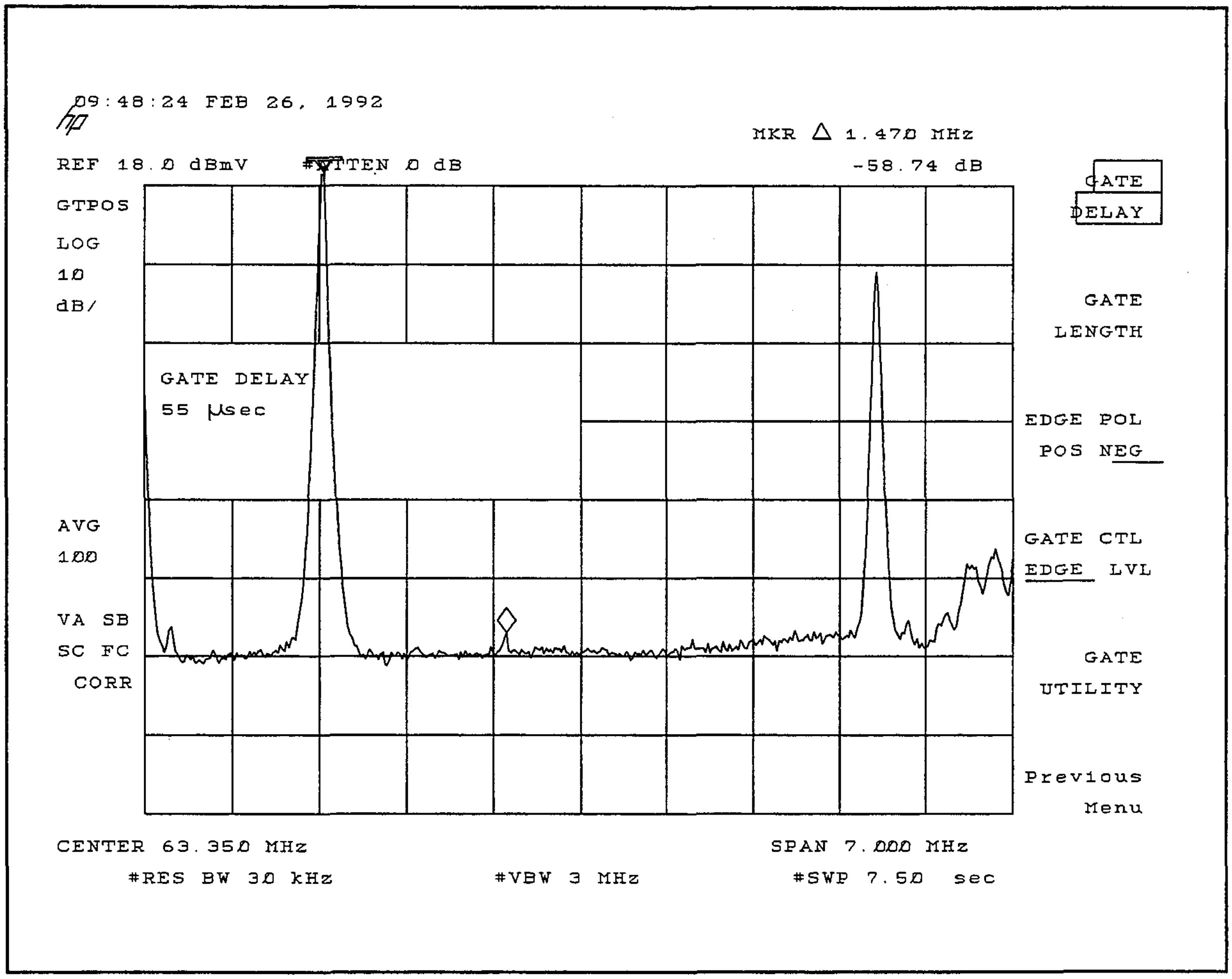
Since the VBW can't be used to average the noise, use (Smooth tra 10;). This command can be executed from the external keyboard. Since the peak is broad, smoothing over 10 buckets (one quarter of a division) is reasonable.

Since the distortion product is closer than 10 dB to the noise floor, its level should be corrected. One way to accomplish this is by looking at the delta level and correcting the peak level accordingly. One also could use the absolute levels to do the correction.

$$\text{Error} = 10\log[10^{0/10} - 10^{-6.6/10}]$$
$$= 10\log[1 - 0.219] = -1.1 \text{ dB}$$

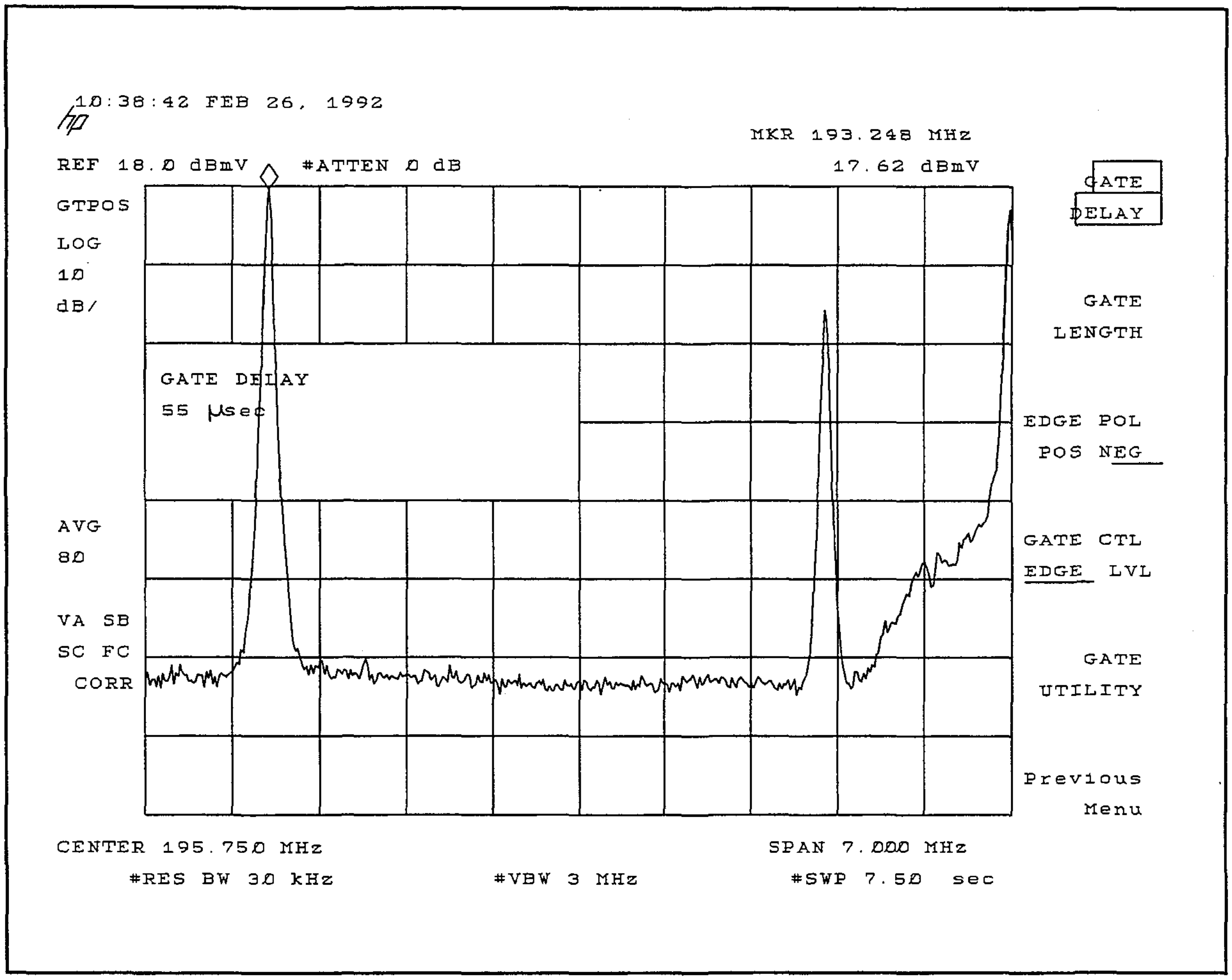
The beat level measures 1.1 dB higher due to the added noise power. Then, subtracting 1.1 dB from the absolute beat level measured would give a more correct beat level.

Most intermods vary in amplitude versus time; therefore, video averaging may conceal this fact. Setting the marker to an intermod and pressing marker to center freq, span 0 Hz and video average off may show its time varying nature, if it is far enough above the analyzer noise floor.



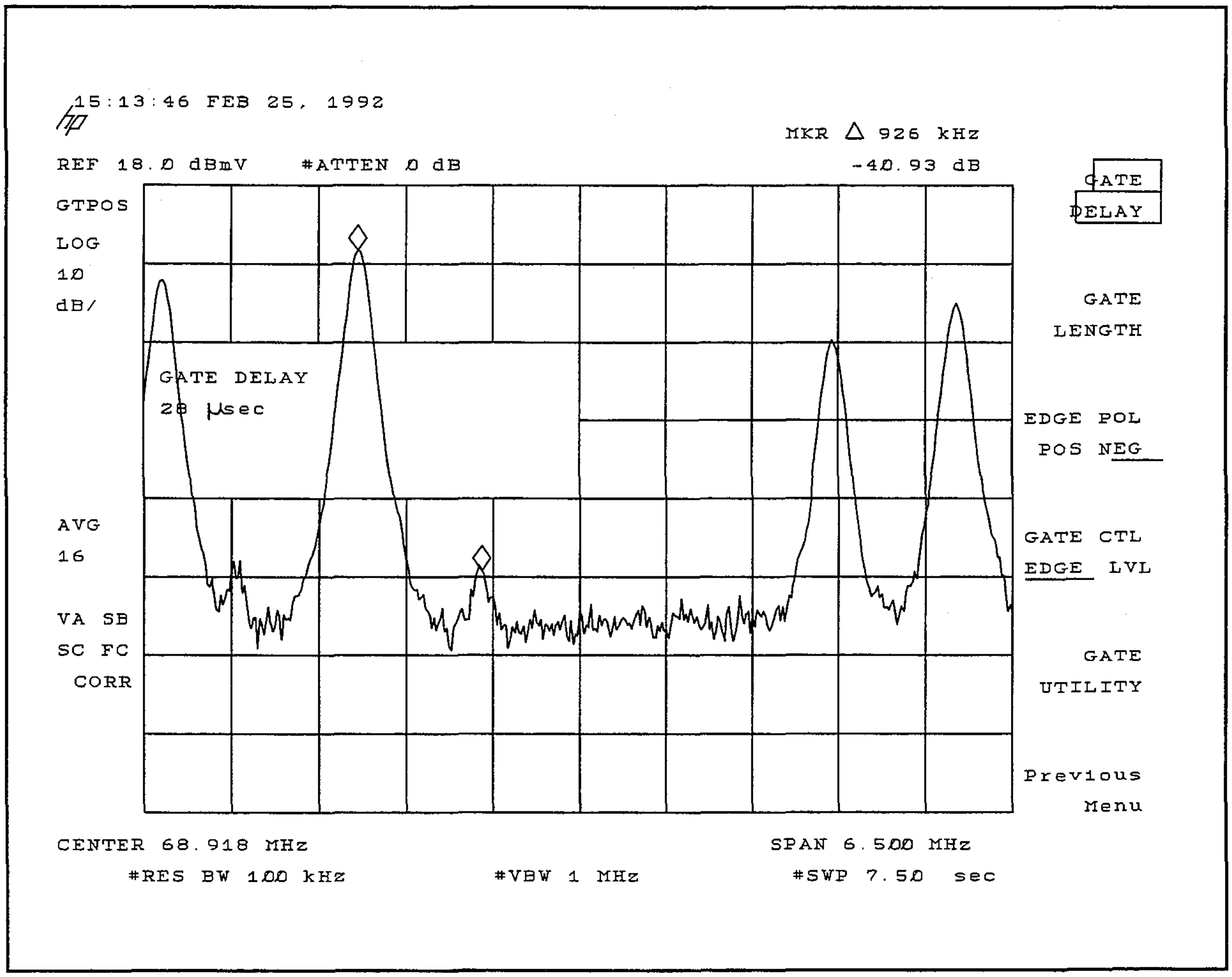
quiet4.hpg

The gated quiet line of channel three shows a +1.5 MHz intermod, possibly from visual - aural + next higher visual in combination with similar beat products. Note also the noise floor slope.



quiet6.hpg

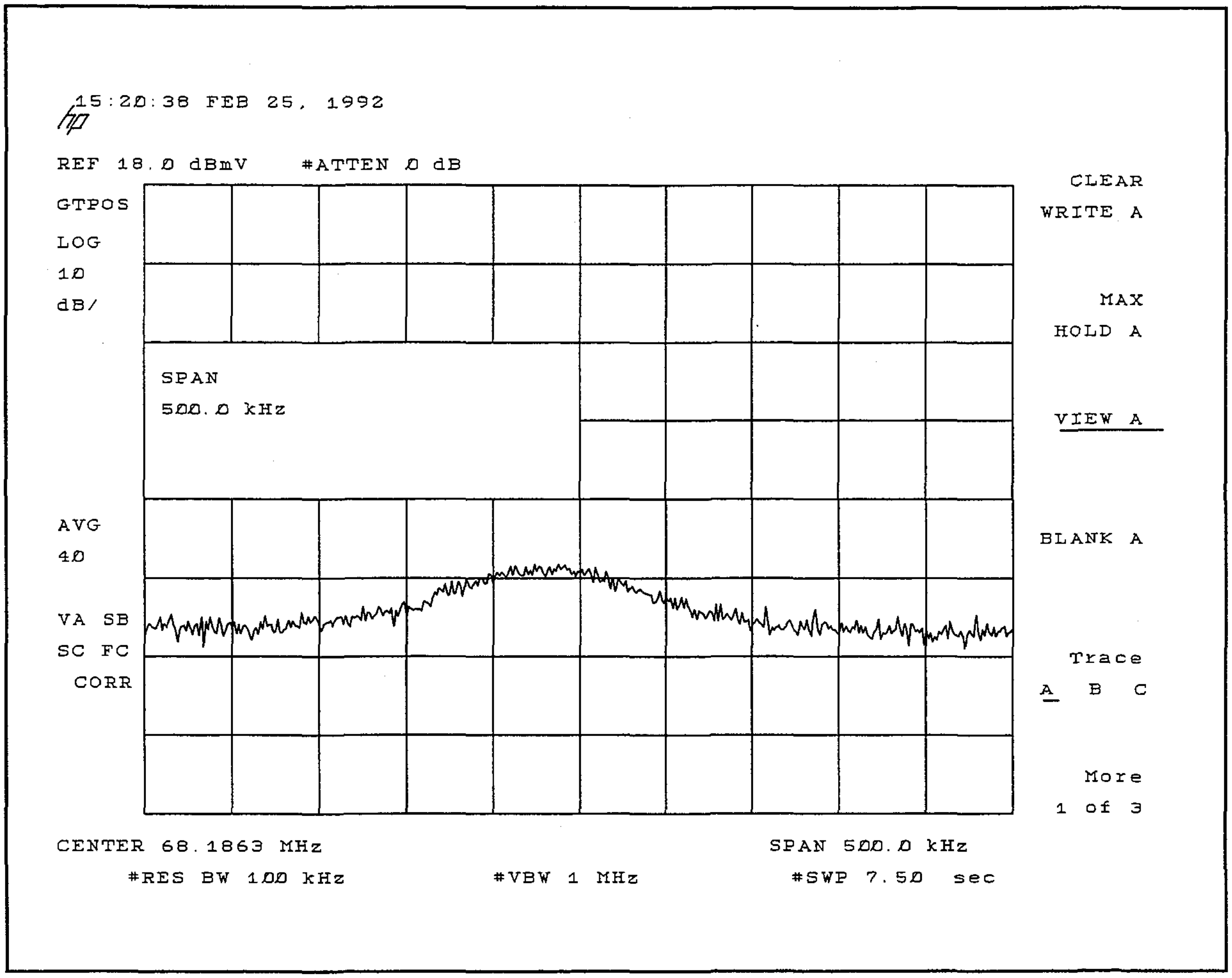
The gated quiet line of channel ten shows a negative noise floor slope. The +750 kHz intermod seen is a CSO product caused by the different spacing of channels 5 and 6 relative to the rest of the channels.



vir4.hpg

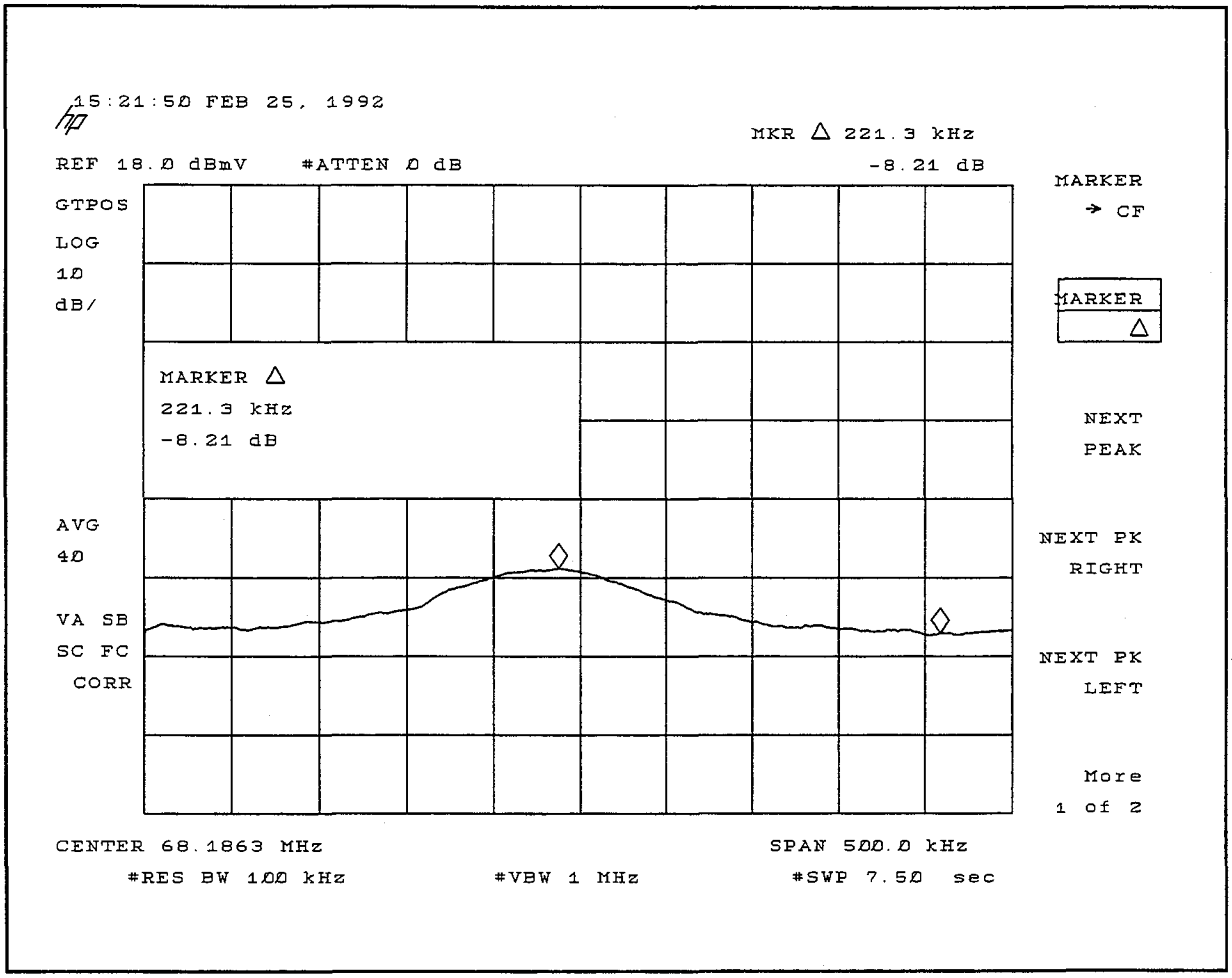
Shown is gated VIR. On the trigger source analyzer, set the TV line number to the vertical interval reference signal. Check if the reference signal is in both fields, and, if so, select vert int (vertical interval). Set the sweeptime to 7.5 sec if the signal is in both fields and 15 sec if not.

Set RBW to 100 kHz so it will respond to less than a full line duration of burst. Set gate delay to 28 μs and gate length to 1 μs. Video average is on. This measurement is a third-order distortion measurement of visual - color + aural carriers at +920 kHz relative to visual carrier. Also seen is a -920 kHz product relative to the visual carrier due to visual + color - aural.



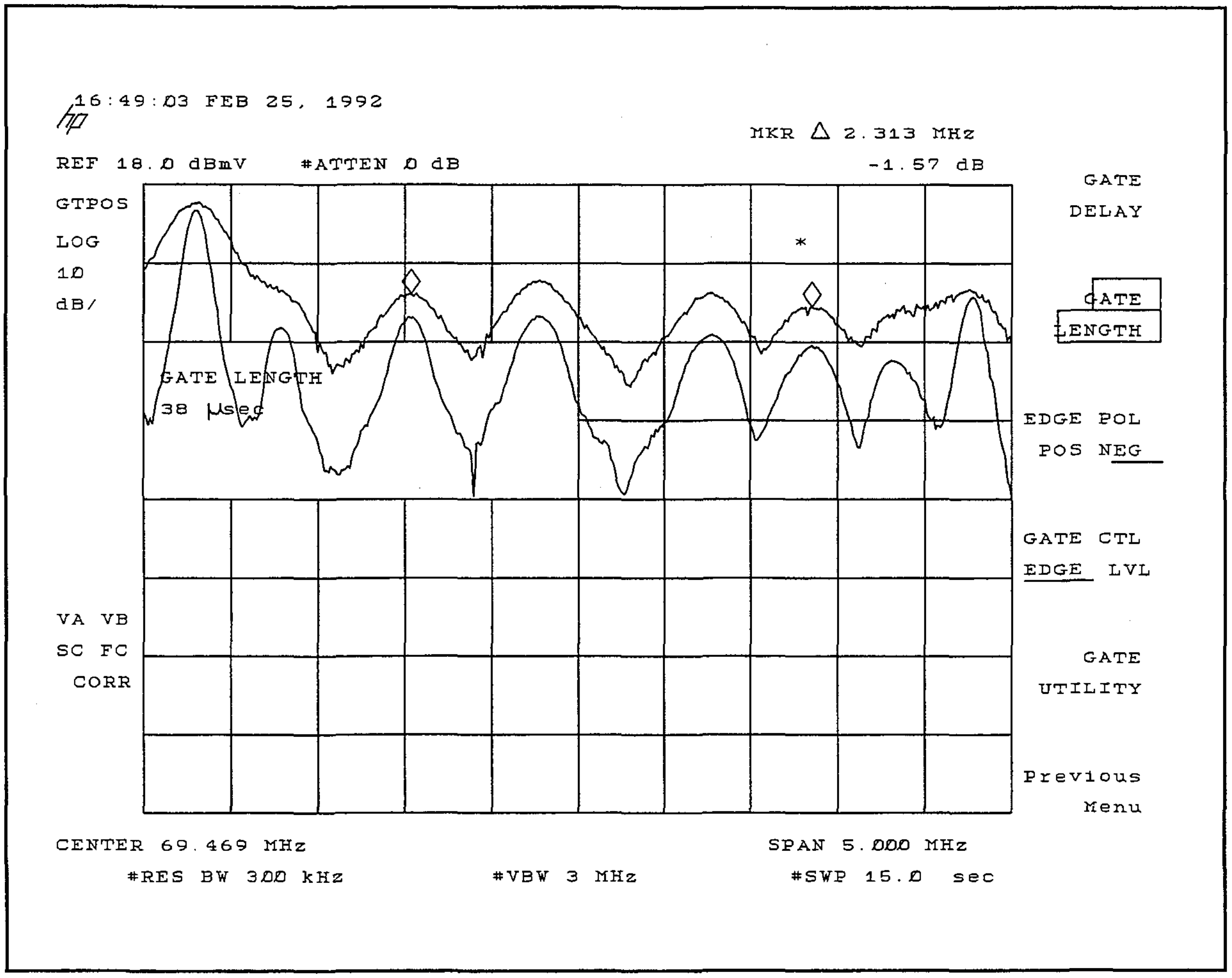
vir6.hpg

Zoom in on the +920 kHz distortion product. This measurement is most useful on broadcast channels or individual channel processors. The intermod level may be very low and difficult to determine, but using a large number of video averages and performing a distortion-near-noise calculation yields a useful result.



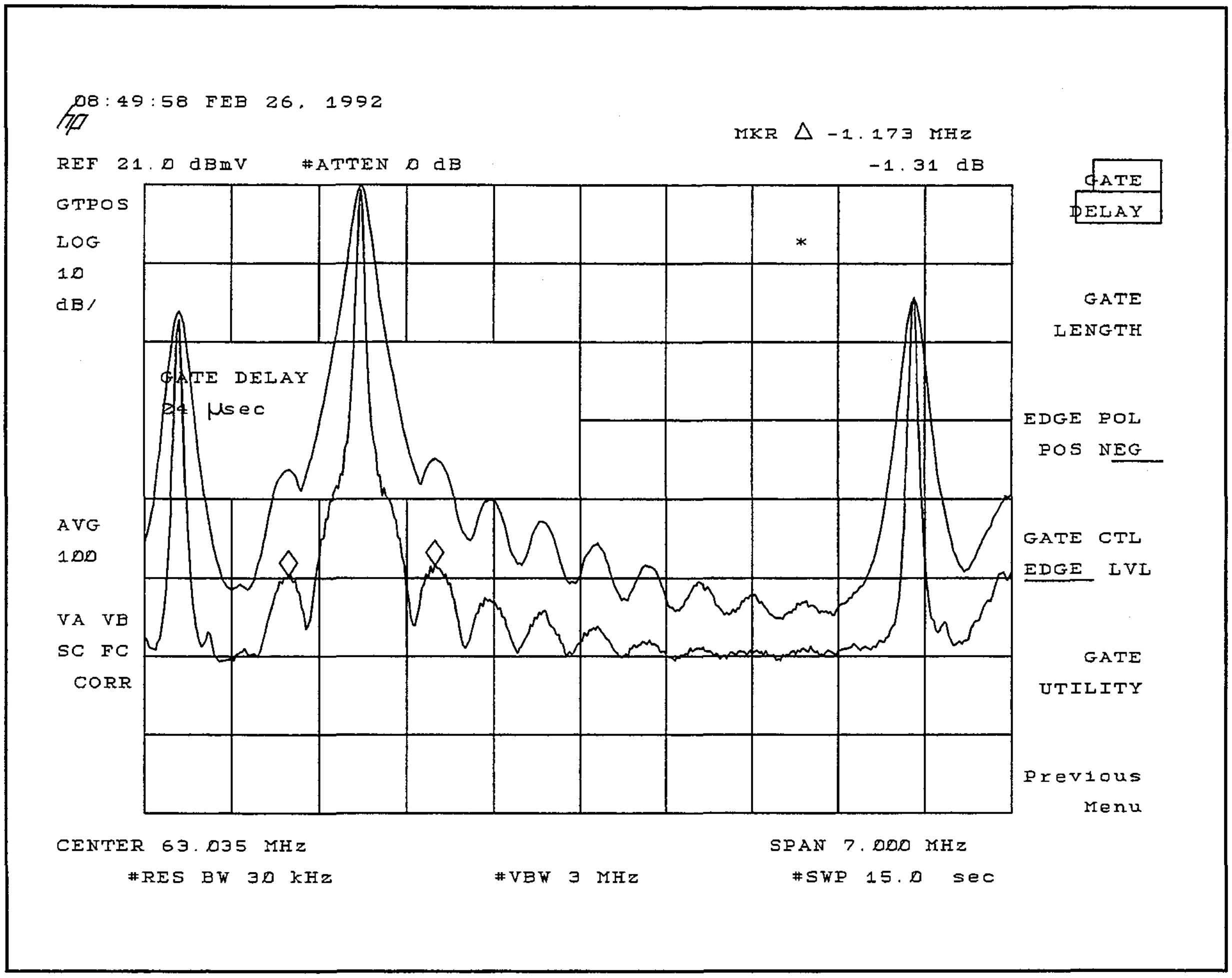
vir6.hpg

Smooth tra 10 also helps resolve the distortion.
Error = $10\log[10^{0/10} - 10^{-8.2/10}] = -0.7$ dB



mb1.hpg

Gated multiburst: Gate delay is 18 μs and gate length is 38 μs. Set the RBW to 100 kHz to resolve all bursts, but due to small pulse width of bursts, a RBW of 300 kHz gives better amplitude accuracy. For 100 kHz RBW, the pulse time would have to be 2/100,000, or 20 μs. But since this is not the case, you would note a reduction of the pulse amplitudes. For 300 kHz RBW, the pulse time would have to be 2/300,000, or 6.66 μs, and this is not the case. That case would be for a worst-case situation, which is not present here. The difference between the pulse amplitudes between the two RBWs is 3 dB for a 1.25 MHz burst, 4.75 dB for 2 MHz, 5.5 dB for 3 MHz, and 6 dB for a 3.58 MHz burst. Cutting the pulse time requirement vs RBW in half would amount to about a 1 dB loss of pulse amplitude for a typical analyzer. Therefore, 300 kHz for RBW is a reasonable value to use to get an idea of the frequency response. If one were to look at both sides of the visual carrier, vestigial sideband filter performance could be viewed, as long as the -1.25 MHz CSO wasn't added in.

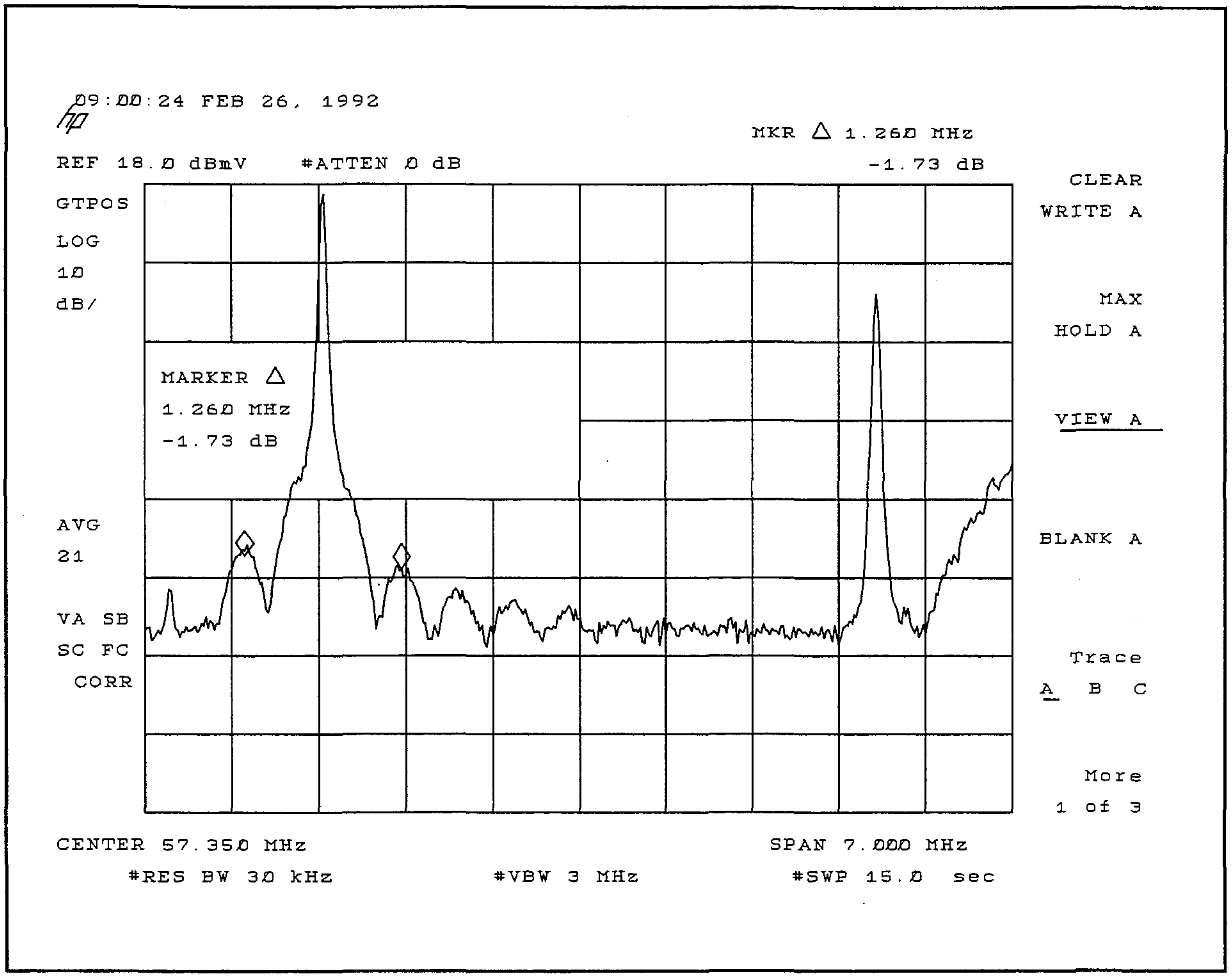


ep2.hpg

Gated Equalizing Pulse of Line 9 Even Field

- One sided sinx/x pulse response
- Bandwidth vs. noise
- Vestigial sideband filter performance
- Group delay effects

The RBW filters are not allowed to charge fully due to the shortness of the pulse for the RBW used. For the gated equalizing pulse, gate delay is 24 μs and gate length is 15 μs. Trigger source is set to line 8, even field, so that the gate pulse will window the line 9 equalizing pulse. The line numbers are not correct at this point because two equalizing pulses per line are present. The depth of the nulls between the lobes is a measure of the steepness of the sync-pulse rise and fall times. The spacing between the nulls is a measure of the sync-pulse width, 1/435 kHz is 2.3 μs. The height of the lobes and the rate at which they roll off is a measure of the channel bandwidth. Overall, this pulse response is a measure of picture quality.



ep3.hpg

Mismatch in first lobe heights could indicate filter misalignment, modulator balance, or group delay problems.

Residual responses on quiet line

- Impedance mismatch
- Cable faults
- Multipath

Responses of delayed horizontal sync or color burst can be viewed by stepping gate delay and a 1 μs gate length through a quiet line.

Summary

Time gating allows one to see

- In-band noise and intermods non-intrusively
- Any location in the RF chain
- Mismatch, faults and multipath effects
- Problem causes can be isolated before taking apart

For the Engineer

- Other portions of test signals can be viewed
- Other test signals can be inserted
- Test signals can be designed for specific use

Gating applications can be extended to many other test signals through thoughtful application of the guidelines presented. With gating, there are fewer restrictions to system analysis, and that analysis becomes much easier to perform.

Several useful references follow.

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