High Definition Analog Component Measurements

Requirements for Measuring Analog Component HD Signals for Video Devices

The transition to digital has enabled great strides in the processing of video signals, allowing a variety of techniques to be applied to the video image. Despite these benefits, the final signal received by the customer is still converted to an analog signal for display on a picture monitor. With the proliferation of a wide variety of digital devices - set-top boxes, Digital Versatile Disk (DVD) players and PC cards - comes a wide range of video formats in addition to the standard composite output. It is therefore necessary to understand the requirements for measuring analog component High Definition (HD) signals in order to test the performance of these devices. When an image is captured by a color camera and converted from light to an electrical signal, the signal is comprised of three components - Red, Green and Blue (RGB). From the combination of these three signals, a representation of the original image can be conveyed to a color display. The various video processing systems within the signal paths need to process the three components identically, in order not to introduce any amplitude or channel timing errors. Each of the three components R'G'B' (the (') indicates that the signal has been gamma corrected) has identical bandwidth, which increases complexity within the digital domain.

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Y', R'-Y', B'-Y', Commonly Used for Analog Component Analog Video		
Format	1125/60/2:1 750/60/1:1	525/59.94/1:1, 625/50/1:1
Y'	0.2126 R' + 0.7152 G' + 0.0722 B'	0.299 R' + 0.587 G' + 0.114 B'
R'-Y'	0.7874 R' - 0.7152 G' - 0.0722 B'	0.701 R' - 0.587 G' - 0.114 B'
B'-Y'	- 0.2126 R' - 0.7152 G' + 0.9278 B'	- 0.299 R' - 0.587 G' + 0.886 B'

▶ **Table 1.** *Conversion of R'G'B' into Y',B'-Y',R'-Y'.*

Y', P'b, P'r Analog Component			
Format	1125/60/2:1 1920x1035 (SMPTE 240 M)	1920x1080 (SMPTE 274 M) 1280x720 (SMPTE 296 M)	525/59.94/1:1 (SMPTE 273), 625/50/1:1 (ITU-R.BT.1358)
Y'	0.701 G+0.087 B'+0.212 R'	0.2126 R'+ 0.7152 G'+ 0.0722 B'	0.299 R'+0.587 G'+0.114 B'
P'	(B'-Y')/1.826	[0.5/(1-0.0722)](B'-Y')	0.564(B'-Y')
P'r	(R'-Y')/1.576	[0.5/(1-0.2126)](R'-Y')	0.713(R'-Y')

▶ **Table 2.** *Conversion of Y',B'-Y',R'-Y' into Y', P'b, P'r.*

To reduce the bandwidth required, we convert the R'G'B' signals into a single luma signal Y' made from portions of the Red, Green and Blue as defined by the equations in Table 1. In order to convert the signal back to its R'G'B' components for final display, we need two other color difference signals - B'-Y' and R'-Y'. These signals have a reduced bandwidth, since the detailed picture information is carried by the full bandwidth luma channel. A simple matrix circuit converts between R'G'B' and Y', B'-Y', R'-Y' allowing bandwidth reduction and easier implementation of digital processing. Conversion of Y', B'-Y', R'-Y' into Y'P'bP'r is often done to allow similar dynamic ranges of the luma and color difference signals. Typical amplitude ranges for R'G'B' signals are 0 mV to 700 -. The conversion to Y' gives an amplitude range of 0 mV to 700 mV but the color difference signals each have different amplitude ranges:

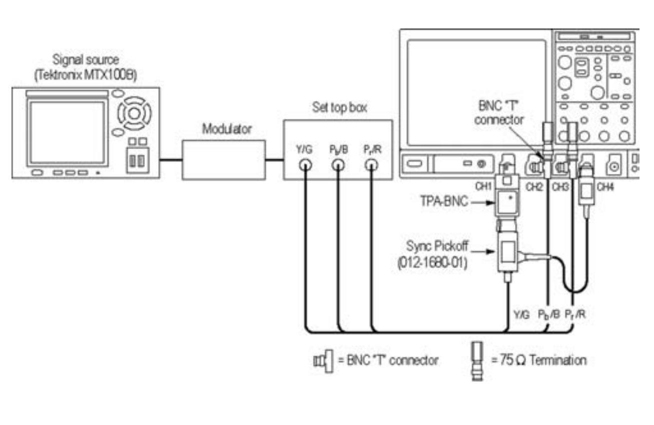
R'-Y' is +/-491 mV for 525 or 625 and +/-551 mV for 1125 & 750

B'-Y' is +/-620 mV for 525 or 625 and +/-650 mV for 1125 & 750

To simplify the process, scaling factors are added to B'-Y' and R'-Y' components so that the dynamic ranges of the signals are +/- 350 mV as shown in Table 2. To indicate this, the values are termed P'b (scaled B'-Y' component) and P'r (scaled R'-Y' component).

There are a variety of different measurement parameters that need to be quantified in analog high definition component systems. Some of these will be similar to those measurements done in the composite domain. These types of measurements are detailed in two Tektronix publications: *Television Measurements - PAL Systems (25W-7075-01)* and *Television Measurements - NTSC Systems (25W-7049-03)*. Composite measurements, however, such as Differential Gain and Differential Phase have little meaning within a component signal. Used exclusively in the composite domain, these tests relate to the measurement of the modulated chrominance gain relative to luma level or the uniformity of chrominance phase to luma level. In analog component video, the chrominance signal is represented by the two separate color difference components. Therefore different measurement methods are employed. The number of different measurements required for quantifying component signals are less than in the composite domain, however the measurements have to be applied to all three components.

▶ **Figure 1.** *VM6000 for analog HD automated measurements.*

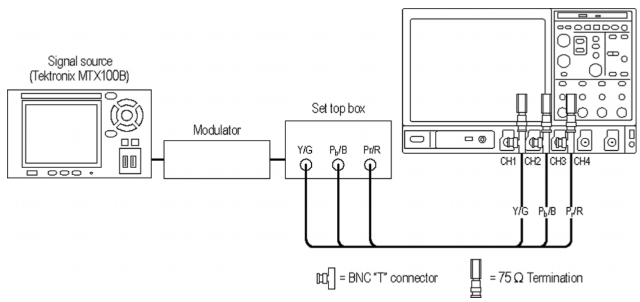


▶ **Figure 2.** *Preferred connection of YPbPr/GBR to VM6000 .*

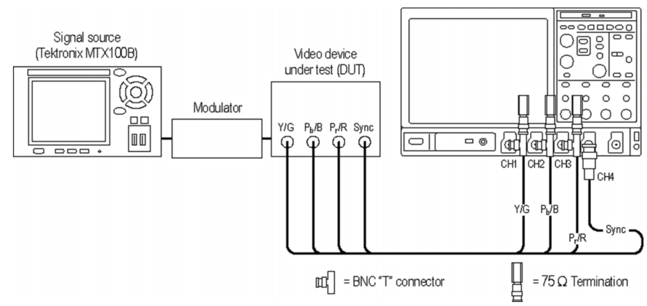
Automated Measurements

Tektronix has developed an automated measurement package for analog component SD and HD video systems, the VM6000 shown in Figure 1. Once configured, the instrument can make a series of automated measurements on the device under test (DUT). Connections to the VM6000 may be configured in a variety of ways, depending upon the type of outputs available from the DUT. Within a component system, the synchronizing signal can be carried on a variety of the channels. Broadcast standard Y'P'bP'r SD format sync, for example, is carried on the Y channel and is a bi-level sync signal). In Y'Pb'Pr' HD formats, however, a tri-level sync is used and may be carried on all channels; in R'G'B' HD formats the sync can be on one or all of the components, carried as a separate sync (RGBS) or with separate H and V sync (RGBHV), as is typical in the VGA outputs of a PC. It is therefore important to set up the VM6000 correctly for the appropriate type of input format being used.

For configurations using either Y'P'bP'r or R'G'B', with composite sync on Y' or G', the system can be set up as shown in Figure 2, with the Y' or G' signal connected to Channel 1 of the VM6000. This configuration provides for accurate Frequency Response and Multiburst measurements while providing a more accurate low-level Noise measurement. The Sync Pickoff accessory, Tektronix part number 012-1680-01, used in conjunction with a TPA-BNC Tekprobe™ BNC adapter, provides a low capacitance connection to the Channel 1 signal and avoids some of the connection problems in other methods of connecting the device under test to the VM6000. The trigger source is set by default to Channel 4.



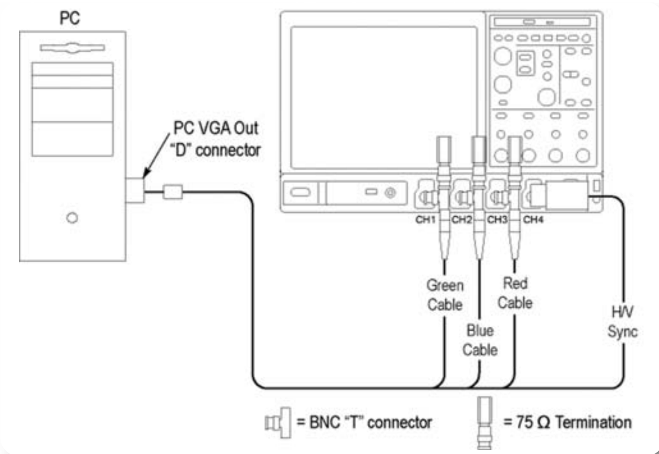
▶ **Figure 3.** *Connection of YPbPr/GBR to VM6000.*



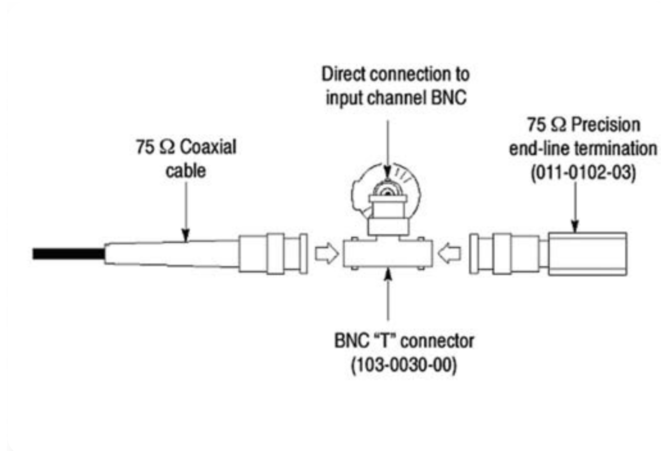
▶ **Figure 4.** *Component connection with separate sync.*

If the sync pickoff fixture is not available, for configurations using either Y'P'bP'r or R'G'B' with composite sync on Y' or Green, the system can be set-up as shown in Figure 3 with the Y' or G' channel connected to Channel 1 of the VM6000. This configuration provides for accurate Frequency Response measurements, but limits the range of the Noise measurement to -65 dB (30 MHz) on the Channel 1 input. In this case, the synchronization for the VM6000 would be set to Channel 1.

A four-wire system that provides a separate sync output from the device under test can be configured as shown in Figure 4. With this approach, synchronization is obtained directly from Channel 4.



▶ **Figure 5.** *PC VGA connection to instrument.*

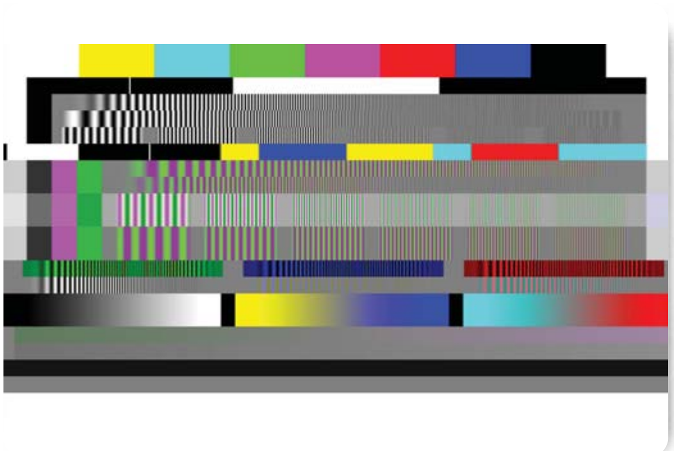


▶ **Figure 6.** *Termination at input to instrument (VM6000 shown).*

In the final configuration, a special cable, Tektronix part number 012-1664-00 VGA Sync Combiner, which provides the three video channels and combines H and V syncs allows direct connection to a PC and correctly interfaces to the VM6000 as shown in Figure 5. This cable combines the separate horizontal and vertical syncs from the VGA output into a composite sync so that it can be directly applied to the Channel 4 input of the device. This configuration is commonly used for testing the 5 wire R'G'B' output from the set-top box.

Termination and Cable Impedance

Improper termination is a very common source of operator error and frustration. If you put two terminators in the signal path, or leave it unterminated, the signal amplitude will be seriously affected. It is therefore essential that you terminate each video signal, using a 75 Ω terminator. When the signal is looped through several pieces of equipment, it is generally best to terminate at the final piece of equipment. The quality of the terminator is also important, particularly if you are trying to measure small distortions. Be sure to select a terminator with the tightest practical tolerances because incorrect termination impedance can cause amplitude errors as well as frequency distortions. Signal cable impedance is also important, to avoid mismatch especially at the higher signal frequencies encountered in HD signals. The signals from the device under test should be connected to the VM6000 via 75 Ω BNC cables that are terminated correctly at the input to the instrument are shown in Figure 6. Note that some input adapters, such as the Tektronix Sync Pickoff accessory, already provide the necessary 75 Ω termination.



▶ **Figure 7.** *Matrix test pattern.*

Test Signal

A variety of test signals are required to measure the performance of an analog component system. Test signals should be repeated for a number of lines to avoid transitional artifacts present in some compressed format signals. However it is not necessary to apply the test signal over the entire field to check conformance of the system. Therefore different test signals can be produced for a certain set of lines and a matrix pattern is formed from the combination of these various patterns. This reduces measurement time by allowing one pattern to be used for a series of measurements. The measurement instrument then makes the appropriate measurements on specific test lines within the matrix pattern. It was necessary to ensure that the signal would support both R'G'B' and Y'P'bP'r formats when designing the matrix pattern. This in turn created the need to compose both a variety of R'G'B' measurement lines and a second set of signals suitable for Y'P'bP'r measurements. The matrix pattern used is shown in Figure 7 and is part of the software package provided with the VM6000. The next section outlines how a variety of these test signals can be used within measurement routines.

Automated Measurement using the VM6000

The instrument is easily configured to make a variety of analog high definition component measurements, simply select, or let the VM6000 automatically select, the standard of the video signal supported and the format (Y'P'bP'r or R'G'B'). It is important to choose the appropriate setup for the synchronization of the instrument to either Channel 1 or Channel 4, depending on the type of device under test. The instrument can be setup to configure itself automatically to the appropriate level and type of signal applied to the inputs. This procedure is normally done only once and saved to speed-up the measurement process. Therefore, if the instrument is used for other functions between automated measurements, the saved setup should be re-selected before continuing. The instrument can also perform averaging for each measurement. This is useful if the signal is noisy and results from the measurements are fluctuating. By increasing the averaging factor more individual measurement results are accumulated into the average, giving a more stable readout. There are twelve fully automated measurement routines provided with the VM6000 covering almost 200 parametric measurements.

Amplitude Measurements – Color Bars

Amplitude measurements are typically performed using the familiar Color Bars test signal that switches on and off components in the R'G'B' format to produce eight possible combinations. There are a variety of different forms of the Color Bars test signal, typically either using a maximum dynamic range of 700 mV = 100% or at 75% with an R'G'B' amplitude of 525 mV. Using Tables 3 and 4, the amplitude ranges for the component Y'P'bP'r are given for the various standards of 100% and 75% Color Bars. Note that component SD and HD formats are conventionally identified by the number of active video lines. For example the familiar 525i or 625i composite format would have the same number of active video lines as a 480i or 576i component signal.

				480/576			1080/720		
	R'	G'	B'	Y'	P'b	P'r	Y'	P'b	P'r
Color Bar	(mV)	(mV)	(mV)	(mV)	(mV)	(mV)	(mV)	(mV)	(mV)
White	700	700	700	700.0	0.0	0.0	700.0	0.0	0.0
Yellow	700	700	0	620.2	-349.8	56.9	649.5	-350.0	32.1
Cyan	0	700	700	490.7	118.0	-349.9	551.2	80.2	-350.0
Green	0	700	0	410.9	-231.7	-293.0	500.6	-269.8	-317.9
Magenta	700	0	700	289.1	231.7	293.0	199.4	269.8	317.9
Red	700	0	0	209.3	-118.0	349.9	148.8	-80.2	350.0
Blue	0	0	700	79.8	349.8	-56.9	50.5	350.0	-32.1
Black	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0

Table 3. *Amplitude ranges for various 100% Color Bars signal formats.*

				480/576			1080/720		
	R'	G'	B'	Y'	P'b	P'r	Y'	P'b	P'r
Color Bar	(mV)	(mV)	(mV)	(mV)	(mV)	(mV)	(mV)	(mV)	(mV)
White	700	700	700	700.0	0.0	0.0	700.0	0.0	0.0
Yellow	525	525	0	465.2	-262.3	42.7	487.1	-262.5	24.1
Cyan	0	525	525	368.0	88.5	-262.4	413.4	60.2	-262.5
Green	0	525	0	308.2	-178.8	-219.7	375.5	-202.3	-238.4
Magenta	525	0	525	216.8	173.8	219.7	149.5	202.3	238.4
Red	525	0	0	157.0	-88.5	262.4	111.6	-60.2	262.5
Blue	0	0	525	59.9	262.3	-42.7	37.9	262.5	-24.1
Black	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0

Table 4. *Amplitude ranges for various 75% Color Bars signal formats.*

Depending on the type of equipment being tested, a variance in the actual values is allowed within some percentage. For instance, the progressive outputs of DVD players can introduce setup to their outputs that can vary the overall measured results. Variations in the level of the components can introduce different hue and saturation values in the displayed picture.

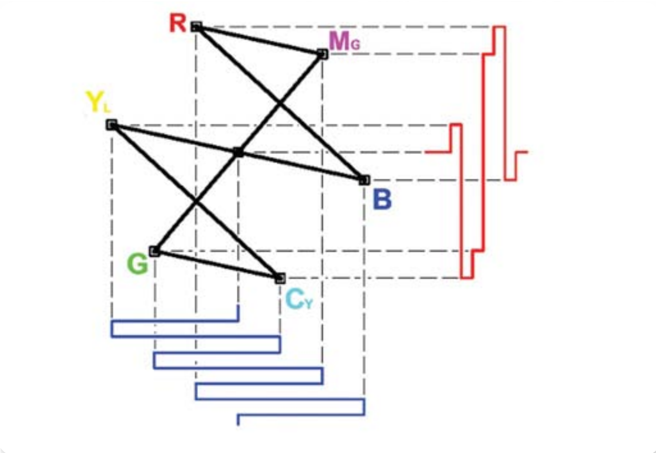
The Color Bars test signal allows the user to check for gain inequalities between the channels and to ensure the signal is not distorted, which could produce severe clipping of the signal.

▶ **Figure 8.** *Color Bars measurement display.*

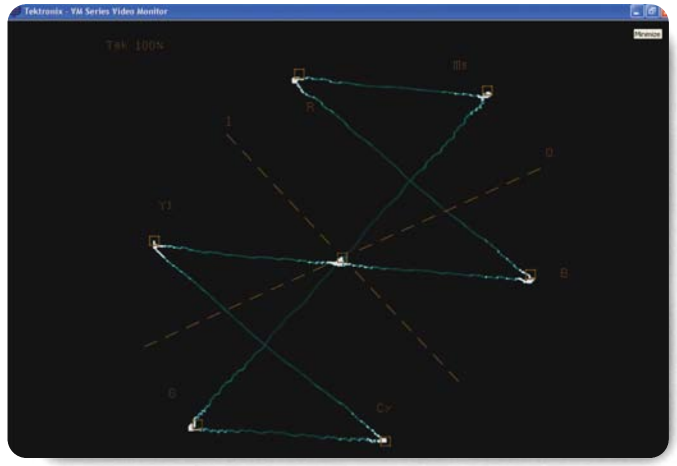
Format	1080p	1080i	720p	480p	576p	480i	576i
Color Bar Line	42-105	21-52 584-615	26-90	43-74	45-60	21-36 284-299	24-39 336-351

The Tektronix Matrix pattern uses a 100% Color Bars signal in order to test the full dynamic range of each component. The Color Bars pattern is located at the top of the matrix pattern; the line numbers at which it occurs are different for each different standard. The line numbers specified are the default values used to generate the test matrix but some systems under test may line shift the image to a different location.

The VM6000 performs the Color Bars measurements by first identifying the relative amplitudes of each of the 3 channels. Eight amplitude measurements are made on each channel, giving a total of 24 measurements made in less than half a second; Figure 8 shows the typical measurement results performed on a 1080i signal. The amplitude level of each of the bar Levels is measured relative to the back porch. Amplitudes are calculated using waveform averaged values within each identified bar. It is therefore important to ensure that the full video line is displayed in the capture window of the instrument if manual setup has been performed on the unit.



▶ **Figure 9.** *Vector display construction.*



▶ **Figure 10.** *Vector display of component Color Bars.*

Within the VM6000 a vector display tool is also available. This allows the user to check the color fidelity of the signal. The vector display is an X-Y plot of the color difference signal B-Y/R-Y with graticule boxes that define the Yellow, Cyan, Green, Magenta, Red and Blue colors as shown in Figure 10. The VM6000 display of an actual 100% Color Bars line is shown in Figure 10 with each color component fitting within the graticule boxes. If the signal does not fit - within the graticule this indicates incorrect amplitude level of the color difference components.

Levels Measurement

This measurement is similar to the Color Bars measurement, and the default measurement setup is measurement of a 100% Color Bars signal. The Levels measurement differs from the Color Bars measurement in that the measurement timing and Levels expected in each of the three video channels across the lines being measured are completely configurable by the operator.

The Levels measurement is useful when a signal differs from the expected colorimetry, for example when a device under test converts a signal rate from 1080i to 480p. A device under test may convert only the rate, but not the colorimetry. The green bar would not be identified as a green bar, and the Color Bars measurement would display a warning. Since the Levels measurement is independent of a standard, the user could set up the measurement for a custom colorimetry.

▶ **Figure 11.** *Levels display of an SD signal with HD colorimetry.*

▶ **Figure 12.** *Custom timing configuration of VM6000 Levels measurement.*

In the studio, a custom camera target could be created using color patches and a reference black patch from the standard color test chart. In addition to the reference patch, up to eight color patches arranged on the same video line could be measured using the automated Levels measurement. Selecting the Configure Levels button, the measurement timing could be set at locations for measurements of particular colors in each color patch, and the level captured to file as the reference under the Configuration>Reference and Limits menus.

This instrument configuration could then be saved under File>Save Setup as a file of type .vmset. Additional cameras could then be matched to the reference camera by observing a continuously updating display of the Relative column Levels measurement values. A custom LIMITS file could also be set up to provide a PASS/FAIL report. This custom Levels setup, including the custom Reference and Limit files may be saved as a .vmset file under the VM6000 application Files>Save Setup menu selection and recalled for future use.

Multiburst Measurement

This Measurement evaluates the ability of the system to uniformly transfer signal components of different frequencies without affecting their amplitude. This amplitude variation is expressed in dB or percent. The reference amplitude (0 dB, 100%) is typically the bar or flag, or some low frequency to which the other frequency components are compared. It is important to know the measured amplitude and frequency at which the measurement was made.

There are three Multiburst test signals - one for R'G'B' using a 100% amplitude and six sinusoidal packets; a 420 mV peak-to peak amplitude (60.0%) for Y'P'bP'r with half bandwidth frequency packets; and a Y'P'bP'r mixed Multiburst signal containing both full bandwidth packets for Y and half bandwidth packets for color difference with 320 mV peak-to peak amplitude (45.7%). It is necessary to use variations of the test signal so that it is compatible when converted from the Y'P'bP'r domain to the R'G'B' domain. Table 5 summarizes the different Multiburst packet frequencies and bar/flag amplitudes used for the various standards. The following table shows the default line locations for the various Multiburst signals.

Format	1080p	1080i	720p	480p	576p	480i	576i
RGB Line	234-297	117-148 680-771	186-217	123-138	173-188	61-68 324-331	88-103 400-415

Format	1080p	1080i	720p	480p	576p	480i	576i
YPbPr Mixed Line	490-553	245-276 808-839	314-377	235-266	301-332	117-132 380-395	152-167 464-479

Format	1080p	1080i	720p	480p	576p	480i	576i
YPbPr Half BW Line	544-617 840-871	277-308	378-441	267-298	333-364	133-148 396-411	168-183 480-495

Format Amplitude	Flag	Packet 1 (MHz)	Packet 2 (MHz)	Packet 3 (MHz)	Packet 4 (MHz)	Packet 5 (MHz)	Packet 6 (MHz)
RGB 1080p	700 mV (0 mV-700 mV)	10	20	30	40	50	60
RGB 1080i & 720p	700 mV (0 mV-700 mV)	5	10	15	20	25	30
Y Mixed BW 1080p	320 mV (620 mV-300 mV)	10	20	30	40	50	60
Y Mixed BW 1080i & 720p	320 mV (620 mV-300 mV)	5	10	15	20	25	30
Pb/Pr Mixed 1080p	320 mV (+/- 160 mV)	5	10	15	20	25	30
Pb/Pr Mixed 1080i & 720p	320 mV (+/- 160 mV)	2.5	5	7.5	10	12.5	15
Y Half BW 1080p	420 mV (560 mV-140 mV)	5	10	15	20	25	30
Y Half BW 1080i & 720p	420 mV (560 mV-140 mV)	2.5	5	7.5	10	12.5	15
Pb/Pr Half BW 1080p	420 mV (+/- 210 mV)	5	10	15	20	25	30
Pb/Pr Half BW 1080i & 720p	420 mV (+/- 210 mV)	2.5	5	7.5	10	12.5	15
RGB 576p & 480p	700 mV (0 mV-700 mV)	2	4	6	8	10	12
Y Mixed BW 576p & 480p	320 mV (590 mV-270 mV)	2	4	6	8	10	12
Pb/Pr Mixed 576p & 480p	320 mV (+/- 160 mV)	1	2	3	4	5	6
Y Half BW 576p & 480p	420 mV (560 mV-140 mV)	1	2	3	4	5	6
Pb/Pr Half BW 576p & 480p	420 mV (+/- 210 mV)	1	2	3	4	5	6
RGB 576i & 480i	700 mV (0 mV-700 mV)	1	2	3	4	5	6
Y Mixed BW 576i & 480i	320 mV (590 mV-270 mV)	1	2	3	4	5	6
Pb/Pr Mixed 576i & 480i	320 mV (+/- 160 mV)	0.5	1	1.5	2	2.5	3
Y Half BW 576i & 480i	420 mV (560 mV-140 mV)	0.5	1	1.5	2	2.5	3
Pb/Pr Half BW 576i & 480i	420 mV (560 mV-140 mV)	0.5	1	1.5	2	2.5	3

▶ **Table 5.** *Multiburst packet frequencies for each video format.*

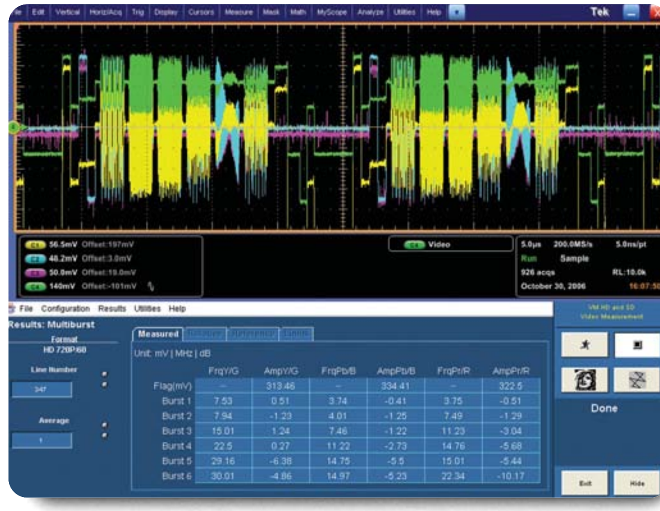
▶ **Figure 13.** *VM6000 Multiburst measurement.*

The VM6000 Automated Video Measurement Set is based on a 1 GHz oscilloscope with full four channel DPO functionality. It therefore has an extremely flat Frequency Response over the narrower bandwidth of video signals, which have a bandwidth of 60 MHz for the 1080p formats, 30 MHz for 1080i and 720p formats, 12 MHz for 576p and 480p formats and less than 6 MHz for 576i and 480i. The instrument's wide bandwidth improves the frequency performance of the application to accurately measure the Multiburst of the video signal. The algorithm used to make the calculations is able to perform effectively under noisy conditions, as well as any translation of the native signal through MPEG compression or to other video formats. The six largest frequency isolated peaks are found within the spectrum of the signal. The original test signal has frequency packets that are sufficiently isolated from each other, however if the device under test has performed significant processing, multiple aliased frequencies can be present within the signal. In such a case, the algorithm chooses the six most isolated peaks within the spectrum display. The frequency packets are displayed on the unit in lowest to highest frequency order. The maximum amplitude of the packet is obtained from a cross-correlation between the pedestal area and a windowed complex sinusoidal.

Figure 13 shows the measurement made on the mixed bandwidth Y'P'b'P'r signal from a test signal generator with little degradation in signal performance. Frequency response problems can produce softening of the picture, with vertical edges becoming fuzzy and smeared. This can happen when the device under test lacks a suitable reconstruction filter with sin(x)/x correction for the video signal. This can lead to a roll-off in the fundamental frequency component of the packet, even though the envelope of the packet may be flat.

In this case, the amplitude results for the highest frequencies may be lower by a few dB, even though the packets may look closer in amplitude on the display. This is because the packet is no longer a pure windowed sinusoid, but has other spectral components. If the extra spectral components are removed by appropriate filtering, the signal envelope will better reflect the actual measurement of Frequency Response for the processed signal at that particular frequency.

▶ **Figure 14.** *Set-top box output of a native 1080i signal.*



▶ **Figure 15.** *Set-top box conversion of native 1080i to 480p standard.*

Figure 14 shows the results from a set-top box producing a native 1080i output. Notice the aliasing of the increasing frequency packets. Depending on the application of the device, these performance limits may be acceptable.

In various set-top boxes, the native format applied to the unit is digitally converted to another display format. When this happens the original packet frequencies from the native test signal will be transposed to other packet frequencies depending on the algorithm used to perform this operation. With reference to the chart below, consider the following example for conversion of a native 1080i signal into a 480p display format. The down conversion process will vary depending on the algorithm that is used to re-sample the 1080i signal into a 480p standard and some of the original frequency packets will be aliased into different frequency packets. This will depend on the sampling frequency and filter characteristics of the output device. The measurement results in Figure 15 show the resultant conversion of a set-top box from 1080i to 480p. In this example, only two packets of the Multiburst signal were correctly processed. The other packets were aliased into a variety of different frequency components.

Generally, conversion to 480p changes the frequency by a factor of (1920/720)x(27/74.176) = 0.9707, with frequency aliases above (27 MHz/2) = 13.5 MHz for Y, R, G & B and either 13.5 MHz or (13.5 MHz/2) = 6.75 MHz for Pb & Pr:

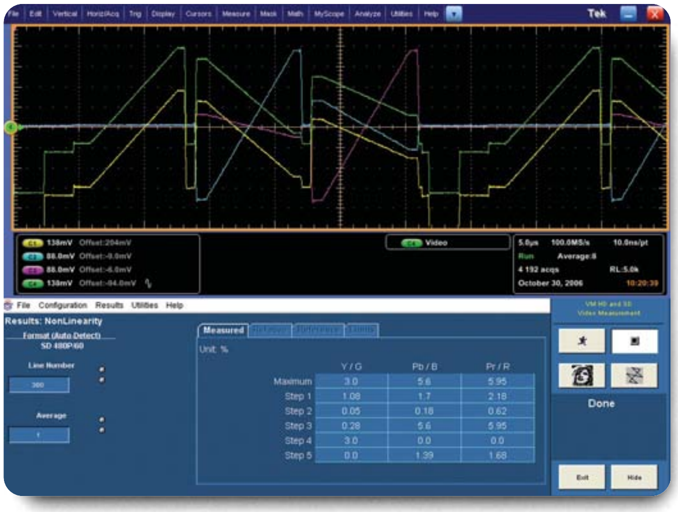
Native 1080i Y	5 MHz	10 MHz	15 MHz	20 MHz	25 MHz	30 MHZ
Full BW 480p Output	4.85 MHz	9.71 MHz	Aliased 14.6 MHz	Aliased 19.4 MHz	Aliased 24.3 MHz	Aliased 29.1 MHz
Native 1080i Pb/Pr	2.5 MHz	5 MHz	7.5 MHz	10 MHz	12.5 MHz	15 MHz
Half BW 480p Output	2.43 MHz	4.85 MHz	Aliased 7.28 MHz	Aliased 9.71 MHz	Aliased 12.13 MHz	Aliased 14.56 MHz

The measurement results show packet frequencies different than the theoretically calculated non-aliased values because they are frequency aliases predicted by Nyquist sampling theory. In addition, the lack of anti-aliasing filtering and/or the lack of reconstruction filtering may cause products to contain multiple frequency components, which may affect the results. Therefore, further analysis is required to characterize the performance of the set-top box, which can be manually done by using the oscilloscope functions of the VM6000 or by using the Frequency Response measurement. However, in such cases the results will show that the Frequency Response deviates substantially from the norm.

Non-Linearity Measurement

Non-linearity is present when gain of the system changes with amplitude level. This amplitude distortion is a result of the system's inability to uniformly process the component information over the entire amplitude range. Comparing the amplitudes at various steps in increments either of a ramp or staircase test signal, the difference between the largest and smallest measurement is expressed as a percentage of the largest step amplitude. The test signal used within the matrix test pattern is a valid ramp which can be used for both R'G'B' and Y'P'bP'r. The valid ramp consists of three ramps within the line, the first of which is a luma ramp used for Y',R',G',B'. The second ramp is used to make the P'b linearity measurement and the third ramp is used for P'r. This is located at the following default lines within the various video standards:

Format	1080p	1080i	720p	480p	576p	480i	576i
Valid Ramp Line	746-808	373-404 936-967	506-569	363-394	429-460	181-196 444-459	216-231 528-543



▶ **Figure 16.** *Non Linear measurement of a DVD player.*

The measurement is made at six equal time intervals across the ramp and the results are given as a percentage deviation from the ideal linear increase in the test signal. The measurement results are displayed in Figure 16 for a typical progressive DVD player output. Notice the overall maximum value is displayed along with the measurement of the five locations across the ramp. In this example the luma signal shows some slight deviation occurring at the middle amplitude levels, which are probably within acceptable limits for the performance of the unit. Most people are not particularly sensitive to luminance Non-Linearity in black and white pictures. If large amounts of distortion are present however, you might notice the loss of detail in the shadows and highlights. These effects correspond to crushing or clipping of the black and white image. However, color shifts due to channel mismatch can be apparent.

Noise Measurement

Noise is present within any electrical system and comes from a variety of natural and man-made sources that can either be random or coherent in nature. An excessive amount of Noise within the system tends to degrade the signal. In extreme cases, Noise can make it difficult for equipment to synchronize to the signal. Errors may become visible at approximately 40 dB signal-to-Noise and produce sparkle or snow effects in the picture. The degree of impairment depends on a variety of factors, including spectral distribution of the Noise.

CCIR Recommendation 576-2 for SD formats provides information on weighting filters used to characterize the Noise spectrum to better match the visibility of Noise in typical viewing conditions. These weighting filters have been modified for each of the HD video formats used within the VM6000 to match the "visibility" of Noise characteristics. In addition to OFF, two weighting filters are provided; a Unified Weighting filter as described in Recommendation 576-2, and an Unweighted Bandwidth filter adjustable by the user from 200 kHz to 250 MHz.

To measure Noise, a pedestal signal is used at a 7.5%, 50% or 100% level for Y', R', G', B' and 0% for P'b and P'r. These signals are located at the following default positions in the various video standards:

Format	1080p	1080i	720p	480p	576p	480i	576i
7.5%	938-1000	469-500 1032-1063	634-659	459-474	525-556	221-236 484-499	264-279 576-591
50%	1002-10064	501-532 1064-1095	660-697	475-490	557-588	237-244 500-507	280-295 592-607
100%	1066-1120	533-560 1096-1123	698-745	491-525	589-620	245-262 508-525	296-310 608-622

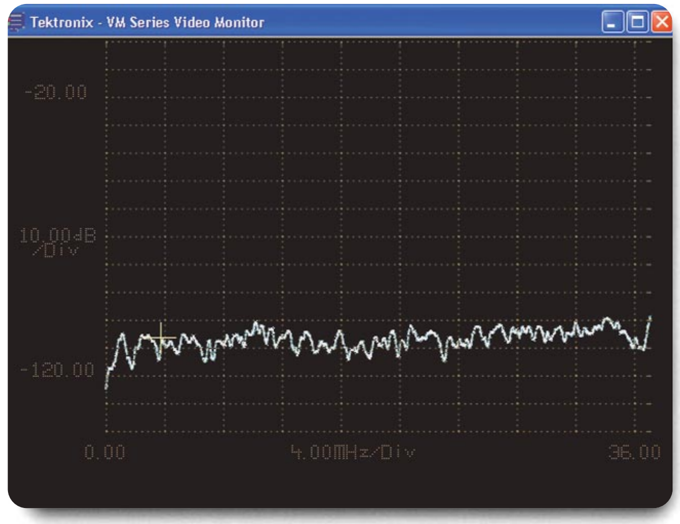
▶ **Figure 17.** *VM6000 Noise measurement.*

Since this measurement disregards hum and tilt, shallow ramp signals can also be used to measure the Noise present within the signal. There is a luma shallow ramp for R'G'B' which is centered at the 50% point and varies from 315 mV to 385 mV (+/- 35 mV). For Y'P'bP'r component signals the luma signal varies from 315 mV to 385 mV (+/- 35 mV) and the color difference signals vary by +/-35 mV centered around 0 mV.

The VM6000 Noise measurement may also be configured using time cursors to measure a quiet segment of any line. Select a line for measurement using the oscilloscope's top taskbar Trig>Video Setup, and select an appropriate format. Trigger on Line# and select a line. Return to the VM6000 application with Analyze>VM SD and HD Video. In the Trigger - Video and In the Results>Noise window, click Set Time Window. Click on Custom in the Time Window Configuration window and drag the time cursors to encompass a part of the line with no high frequency disturbances. Click Apply and run the Noise measurement. Noise will be measured in the selected time-window of the selected line, as shown in Figure 18.

Format	1080p	1080i	720p	480p	576p	480i	576i
YPbPr Shallow Ramp	410-472	405-436 968-999	570-601	395-426	461-492	197-212 460-475	232-247 544-559
RGB Shallow Ramp	474-936	437-468 1000-1031	602-633	427-442	493-524	213-220 476-483	248-265 560-575

▶ **Figure 18.** *Set time cursors can define Noise measurement interval in a complex signal.*



▶ **Figure 19.** *VM6000 Noise spectrum display from a DVD player.*

A spectrum display is also available within the Noise measurement application. This measurement shows the Noise power vs. frequency present within the signal. In order for this display to be calculated the VM6000 must be set-up in Configuration>Operation>Run Mode>Continuously. The spectrum display can show specific Noise-frequency components which maybe interfering with the video output as shown in Figure 19, such as mains frequency hum. This would show up as an amplitude spike around the 60 Hz or 50 Hz region of the display. Hum can produce a light and dark banding moving vertically through the picture.

▶ **Figure 20.** *Channel Delay measurements.*

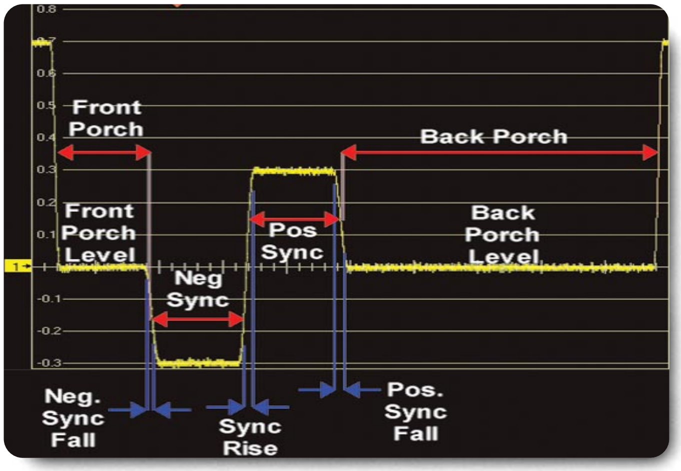
Channel Delay Measurement

Channel Delay measurements are used to verify the relative timing of the three video channels. It is important when making this measurement to ensure that the cables used to connect the DUT and VM6000 are of the same length for each signal path otherwise errors in the results can occur. Thus it is important to either trigger on Channel 1 or use the special high impedance, low capacitance, high frequency fixture to connect the sync component to Channel 4. The delay can arise through inequality in the different paths for each signal. In video systems, a Bowtie signal has been used to characterize the delay between each channel. (For further information please refer to the Tektronix application note *Solving the Component Puzzle, 25W-7009-02.)* However, this requires a special test signal, which may be degraded by processed systems such as MPEG compression or Noise.

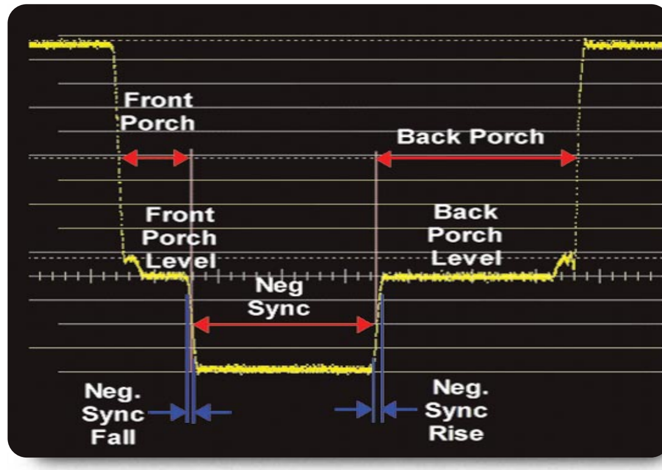
Therefore, an algorithm was developed within the VM6000 which detects cross-correlation between the channels using a standard sweep signal. Additionally, other types of highly correlated signals such as Multiburst or chirps or even live program material can also be used. If a measurement cannot be performed on the signal selected because of the lack of cross-correlation between the channels, the display will show "---" for each channel and an associated "low correlation between channels" warning message may be observed. The measurement finds the maximum cross-correlation of the transitions of the signal between each pair of channels. The delay corresponding to maximum cross-correlation is obtained and displayed in time. A variety of test line signals can be used for Channel Delay provided there is good correlation between the channels. The following test signal lines contain sweep signals for use with R'G'B' or Y'P'bP'r formats at the default locations. The measurement results are shown in Figure 20; each Channel Delay is compared against the other. The positive number for the measurement of channel Pb & Pr indicates that there is a delay in Pb with respect to Pr of approximately 0.33 ns. A positive value of the measurement of Y to Pb indicates there is a delay of Y with respect to Pb of approximately 1.45 ns. The delay measurement result is the time shift required to obtain maximum cross-correlation between the respective parts of the signals. This shift or delay may, in some cases, be frequency dependent. Group delay plots may be obtained by measuring the delay of various narrow band signals.

Format	1080p	1080i	720p	480p	576p	480i	576i
RGB HF Sweep Line	138-200	69-100 632-663	122-153	91-106	125-156	45-52 308-315	56-71 368-383

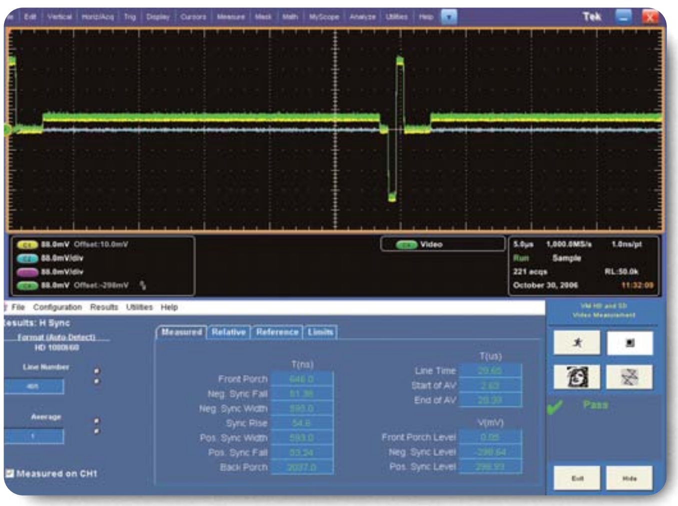
Format	1080p	1080i	720p	480p	576p	480i	576i
YPbPr HF Sweep	362-424	181-212 744-775	250-281	171-202	237-252	85-100 348-363	102-135 432-447



▶ **Figure 21.** *HD Tri-Level Sync Timing measurements.*



▶ **Figure 22.** *SD Bi-Level Sync Timing measurements.*

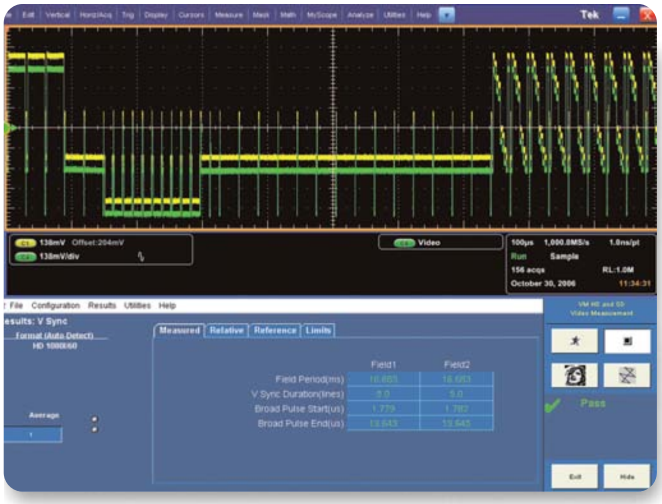


▶ **Figure 23.** *VM6000 Horizontal Sync measurement results for an HD signal.*

Horizontal Sync Measurement

This measurement checks the signal timing and amplitude for the horizontal blanking interval of the appropriate video standard to ensure that synchronization signals conform to the standard. Any of the active lines within the matrix test signal can be used to perform this measurement. If another signal is used, the active video signal amplitude should be greater than 7.5% in order to measure front and back porch accurately. If the signal is not of sufficient amplitude, the VM6000 may not be able to make front and back porch width measurements. All amplitudes are measured relative to back porch.

Timing intervals are measured at the 50% point of the rising or falling edges of the signal. Rise and fall time measurements are made between the 10% and 90% points. Start of Active Video (AV) and End of AV are measured from the reference point defined in the signal standard; the positive-going zero crossing of the tri-level HD sync, or the 50% leading edge of the SD bi-level sync. Figure 21 shows the relative positions of the measurements made by the VM6000 for HD signals and Figure 22 the relative positions for SD measurements. The results are displayed as shown in Figure 23.



▶ **Figure 24.** *VM6000 Vertical Sync measurement results for an HD signal.*

Vertical Sync Measurement

The Vertical Sync measurement, as shown in Figure 24, checks the signal timing for the vertical blanking interval of the appropriate video standard to ensure that synchronization signals conform to the standard. Measurements will be reported using any video signal, but it is important that start and end of active video be clearly defined. If the video signal is not of sufficient amplitude above the black level, the VM6000 may not be able to make front and back porch width measurements.

The Vertical Sync measurement reports the field period, or periods for an interlaced signal, along with the number of broad pulses which occur with a negative average picture level (APL) to easily identify the Vertical Sync to low frequency analog detectors. The appropriate signal standard identifies these values along with the correct broad pulse start and end time relative to the horizontal sync timing reference.

Frequency Response Measurement

Various devices such as set-top boxes can reformat the video signal such that frequencies maybe shifted from their original values in their native video format. Aliasing components may occur within the signal for instance when a native 1080i signal is converted to 480p by the device. It is useful to quantify the Frequency Response of the system and ensure the system uniformly transfers the different frequency components without affecting their amplitudes.

The Frequency response measurement allows the user to define either a point in time (measured from the Sync Timing Reference) or to find a specific frequency within the active line. A sweep signal is typically used to make this measurement but a Multiburst signal can also be used. The signal must start with a flag (low frequency amplitude bar) at the front of the signal. Both sweeps signals and Multiburst signal within the Tektronix matrix signal can be used.

These signals are available in the Tektronix matrix signal on lines indicated in the table to the right. The more cycles present in the burst, the more robust and accurate the measurement will be. However a burst with less than two cycles present within the signal is not recommended to be used within the measurement algorithm.

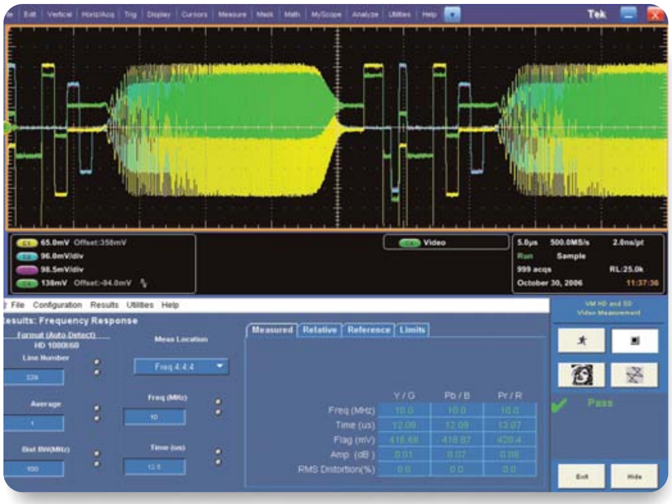
Format	1080p	1080i	720p	480p	576p	480i	576i
RGB HF Sweep Line	138-200 632-663	69-100	122-153	91-106	125-156	45-52 308-315	56-71 368-383

Format	1080p	1080i	720p	480p	576p	480i	576i
RGB LF Sweep Line	202-432	101-116 664-679	154-185	107-122	157-172	53-68 316-323	72-87 384-399

Format	1080p	1080i	720p	480p	576p	480i	576i
YPbPr Half BW Line	362-424	181-212 744-775	250-281	171-202	237-252	85-100 348-363	102-135 432-447

Format	1080p	1080i	720p	480p	576p	480i	576i
YPbPr Full BW Line	226-488	213-244 776-807	282-313	202-234	253-268	101-116 364-379	136-151 448-463

If the user selects a specific frequency for the measurement to be made on there are two choices for the way in which the frequency is found across the channels. In Freq4:4:4 mode the measurement routines find the same frequency in each of the channels this would typically be used for RGB full bandwidth channels. The other choice of Freq4:2:2 would typically be used for YPbPr formats where the specified frequency value would be found on Channel 1 (Y) and the frequency value would be divided by two for the channels two and three (Pb/Pr). In this way the same point in time would be found across the Y and Pb/Pr channels for that specific frequency.



▶ **Figure 25.** *VM6000 Frequency Response measurements.*

The measurement algorithm first finds the portion of the signal at the time or frequency specified by the user on each channel. The measurement routine then displays the time and frequency of the specified location. A measurement of the amplitude signal is then made relative to the flag amplitude and the resultant is displayed in dB. The flag amplitude is also displayed. A 3µs raised cosine window is centered on the measurement location. The spectrum calculation yields the threshold spectral components and shows signal dependent distortion components such as aliases and other nonlinear distortions present. The percentage of the distortion is calculated from the square root of the sum of the squares of the distortions components divided by the fundamental magnitude. The results are then tabulated as shown in Figure 25.

▶ **Figure 26.** *VM6000 Short Time Distortion measurements*

Short Time Distortion Measurement

This measurement shows the effect of linear distortion on the picture quality of the signal. These distortions affect amplitude and delay versus frequency. This can be seen in the picture as fuzzy edges between transitions or ringing before or after the transition. To measure the impact of these types of distortions a pulse and bar signal is typically used. The pulse is used for the K2T measurement and the bar is used for the rest of the measurements. The rise and fall time of these pulses are typically characterized by a T or 2T response, where T is defined:

$$T = \frac{1}{2F_{max}}$$

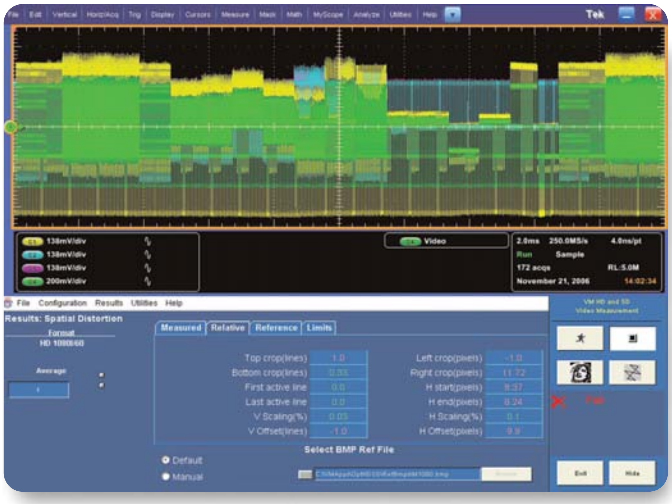
F_{max} = Maximum frequency bandwidth of video format

The K factor rating systems maps linear distortions of 2T pulses and line bars onto subjectively determined scales of picture quality. The various distortions are weighted in terms of impairments to the picture. The K2T is a weighted function of the amplitude and time distortions occurring before and after the 2T pulse. The characterization of these types of distortion has been well defined in standard definition formats but it was necessary to transpose these types of measurements into other HD and computer formats. The Short Time Distortion measurement measures the rise and fall time, overshoot and undershoot, settling time of the rising/falling edges and the K2T response.

The rise and fall time are calculated on the bar using the 10% and 90% points. The result is displayed in ns. The overshoot is calculated as the highest excursion of the signal on the positive edge relative to the Vmax steady state. Undershoot is calculated as the lowest excursion of the signal on the negative edge relative to Vmin steady state. These two results are displayed in % using the steady state value as a reference. The settling time on the rising edge is measured from the end of the overshoot to the point where the amplitude of the video is ringing down to +/-5% of the final steady state value.

Format	1080i	720p	480p	576p	480i	576i
RGB Line	53-68 616-631	90-121	75-90	77-108	37-44 300-307	40-55 352-367

Format	1080i	720p	480p	576p	480i	576i
YPbPr Line	149-180 712-743	218-249	139-170	205-236	69-84 332-347	104-119 416-431



▶ **Figure 27.** *Spatial Distortion relative to a reference bitmap.*

Spatial Distortion Measurement

The Spatial Distortion measurement provides a point-by-point positional comparison of the incoming signal vs. a stored reference bitmap version of the same signal. From this comparison, the VM6000 determines the horizontal start and end, vertical start and end, horizontal and vertical size and offset, and any spatial offsets within the field or frame. This provides a measurement of any undesirable distortions created by a device under test when an original test signal in one format, for example, is converted to another format. The Reference and Limits files may be custom configured for this measurement to match the expected output of a device under test. The measurement also provides an indication as to whether measurement line numbers might have to be adjusted to successfully make other automatic measurements. Any changes to default values may then be stored for later recall in a .vmset file under the File>Save (or Recall) Setup menu.

As with other automatic VM6000 measurements, the Spatial Distortion Relative tab provides a quick reference for measurement against ideal values. This report, Figure 27, indicates the picture is moved down one line (Top Crop and Vertical Offset), and 1/3 of the bottom line is not visible. The left of the picture is not cropped, but the active video starts to the right about 10 pixels after the expected position. Vertical and Horizontal scaling are well within 1%. The Limit file values have been exceeded for Vertical and Horizontal position, reporting Fail. These deviations could be acceptable for many applications and the Reference and Limits files could be adjusted for an appropriate match to expected performance. Consumer equipment, for example often offers a selection of format conversions for display of one signal aspect ratio, perhaps 16x9 on a legacy 4x3 aspect ratio display.

▶ **Figure 28.** *VM6000 Horizontal Sync Jitter measurements.*

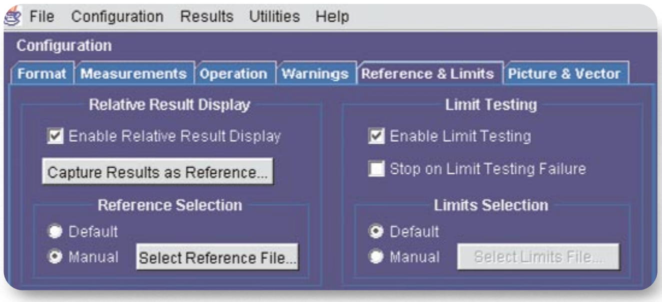
Horizontal Sync Jitter Measurement

Jitter is the rapid instability of a signal compared to some stable reference. When the self-clocked video tries to lock to a stable reference, for example, and succeeds in hanging on, jitter is the measurement of how well. The reference and video signals are locked in step, but there is some wiggle between the two. This is jitter, usually measured in nanoseconds, (ns), in a broadcast video signal.

Wander is the drift a signal experiences over time, typically defined by a slow rate up to 10 or 20 Hz. This low frequency is often easier to separate from the video synchronizing information which occurs at a higher rate. Video signals broadcast to the public or intended for replay by consumer devices are generally clocked at frequencies well within the limits of display devices.

The Horizontal Sync Jitter measurement displays rapid (Jitter) and longer term (Wander) timing instabilities in the horizontal synchronizing signal. The operator may select to display a peak jitter in terms of probability, or specify a probability a specified jitter magnitude is likely to occur. The user may also specify demarcation frequencies to isolate instabilities. For example a low pass filter cutoff frequency to pass long term wander, ignoring short term jitter variations, and a high pass cutoff filter to favor the measurement of higher speed jitter.

Jitter is measured in terms of ns from ideal coincidence with the horizontal sync reference edge, and Wander in terms of drift rate.



▶ **Figure 29.** *Reference & Limits configuration.*

Measurement Reporting and Limit Testing

When making a number of measurements on your device under test or testing the quality of the device on a production line it is essential to set some limits above or below which the unit will fail to meet your standard specifications. Within the VM6000 the user can select default reference and limits files from which the measurement range can be defined or create their own specific *.CSV files. When the measurements falls outside this range the user can be warned that the device failed a specific test or the test routine can be halted so that corrections can be made to the device.

If you wish to create a specific set of reference and limits files for a certain format import the default reference/limits file into a spreadsheet program that allows importation of *.CSV files. Modify the files to meet your specific requirements and then save the file within the VM6000 folder system. In the VM6000 configuration menu select your new reference/limits as shown in Figure 29. Tables 6 and 7 show partial examples of the default limits and default reference spreadsheets which can be edited for the users specific requirements.

Default Reference File

This Default Reference File is provided AS IS without warranty of any kind and is intended to be used as a template only. WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE ARE EXPLICITLY DISCLAIMED. Copyright 2006 Tektronix. Permission to use and create derivatives in conjunction with VM6000 family products hereby granted. All other rights reserved.

Format:	**1080i/60**
Color Space:	**YPbPr**
	Ref
Channel Delay	
YtoPb (ns)	0
YtoPr (ns)	0
PbtoPr (ns)	0
ColorBars	
Y Level (mV)	
White	700
Yellow	649.5
Cyan	551.2
Green	500.6
Magenta	199.4
Red	148.8
Blue	50.5
Black	0
Pb Level (mV)	
White	0
Yellow	-350
Cyan	80.2
Green	-269.8
Magenta	269.8
Red	-80.2
Blue	350
Black	0
Pr Level (mV)	
White	0
Yellow	32.1
Cyan	-350
Green	-317.9
Magenta	317.9
Red	350
Blue	-32.1
Black	0

▶ **Table 6.** *Part of Reference Limits File.*

Default Limit File

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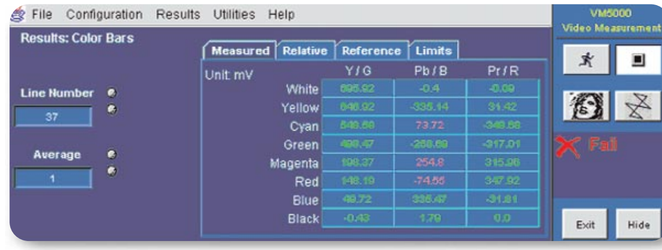
Format: 1080i/60

Color Space: YPbPr

		Low	High
Channel Delay			
YtoPb (ns)		-10	10
YtoPr (ns)		-10	10
PbtoPr (ns)		-10	10
Color Bars			
Y Level (mV)			
White		665	735
Yellow		617	681.98
Cyan		523.64	578.76
Green		475.57	525.63
Magenta		189.43	209.37
Red		141.36	155.4
Blue		47.5	53.5
Black		-5	5
Pb Level (mV)			
White		-5	5
Yellow		-367.5	-332.5
Cyan		76.19	84.21
Green		-283.29	-256.31
Magenta		256.31	283.29
Red		-84.21	-76.19
Blue		332.5	367.5
Black		-5	5
Pr Level (mV)			
White		-5	5
Yellow		-29.1	-35.1
Cyan		-367.5	-332.5
Green		-333.8	-302
Magenta		302	333.8
Red		332.5	367.5
Blue		-35.1	-29.1
Black		-5	5

▶ **Table 7.** *Part of Default Limits File.*

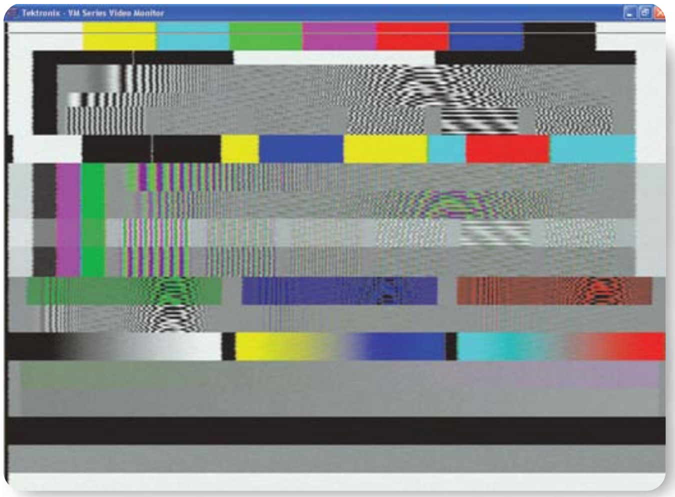
▶ **Figure 30.** *Relative to reference results for a Color Bars signal.*



▶ **Figure 31.** *Pass (green) or fail (red) limits testing of a Color Bars signal.*

When the reference limits and limit testing are enabled, three additional measurement tabs are available. If the reference is enabled then the relative to reference and reference values are shown. The relative to reference shows the deviation from the original reference values. It is possible while making measurement to capture the results from your device as a reference. Figure 30 shows a relative to reference measurement made on a Color Bars signal either in mV or as a percentage.

When limits testing is enabled the measured values change from white measurement values to either green or red depending on whether the measurement passes or fails the limits testing. As shown in Figure 30 and 31 this measurement of Color Bars fails to pass the required limits testing for one of the Color Bars amplitudes in the Pb/B channel. The values in red indicate that these specific values did not pass the limits testing and a red X symbol and Fail indicator is showed on the right hand side of the measurement. The user can select the reference tab to show the current reference values being used and select the limits tab to show either the maximum or minimum Limits being used for this measurement.



▶ **Figure 32.** *Picture display.*

Picture display

While making measurements on your device under test it can be useful to investigate that your measurement are made using the correct video line in the test matrix and that your device under test is not overlaying a on-screen menu which would interfere with measurements results. A Display Picture mode, Figure 32, is available to provide a representative image of the current signals connected to the input of the VM6000.

Conclusion

Measurement of High and Standard Definition analog component video signals is carried out efficiently and competently using the Tektronix VM6000 Automated Video Measurement Set. Operating over a wide range of component video standards, the VM6000 performs quickly and accurately measurements that, even if possible manually, would be too time-consuming to consider.

The VM6000 provides a development and design validation tool for the Engineer; a production quality tool for manufacturing; and ultimately, a tool assuring a product providing a potential for customer satisfaction.

Contact Tektronix:

ASEAN / Australasia (65) 6356 3900
Austria +41 52 675 3777
Balkan, Israel, South Africa and other ISE Countries +41 52 675 3777
Belgium 07 81 60166
Brazil & South America (11) 40669400
Canada 1 (800) 661-5625
Central East Europe, Ukraine and the Baltics +41 52 675 3777
Central Europe & Greece +41 52 675 3777
Denmark +45 80 88 1401
Finland +41 52 675 3777
France +33 (0) 1 69 86 81 81
Germany +49 (221) 94 77 400
Hong Kong (852) 2585-6688
India (91) 80-22275577
Italy +39 (02) 25086 1
Japan 81 (3) 6714-3010
Luxembourg +44 (0) 1344 392400
Mexico, Central America & Caribbean 52 (55) 5424700
Middle East, Asia and North Africa +41 52 675 3777
The Netherlands 090 02 021797
Norway 800 16098
People's Republic of China 86 (10) 6235 1230
Poland +41 52 675 3777
Portugal 80 08 12370
Republic of Korea 82 (2) 528-5299
Russia & CIS +7 (495) 7484900
South Africa +27 11 254 8360
Spain (+34) 901 988 054
Sweden 020 08 80371
Switzerland +41 52 675 3777
Taiwan 886 (2) 2722-9622
United Kingdom & Eire +44 (0) 1344 392400
USA 1 (800) 426-2200

For other areas contact Tektronix, Inc. at: 1 (503) 627-7111

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