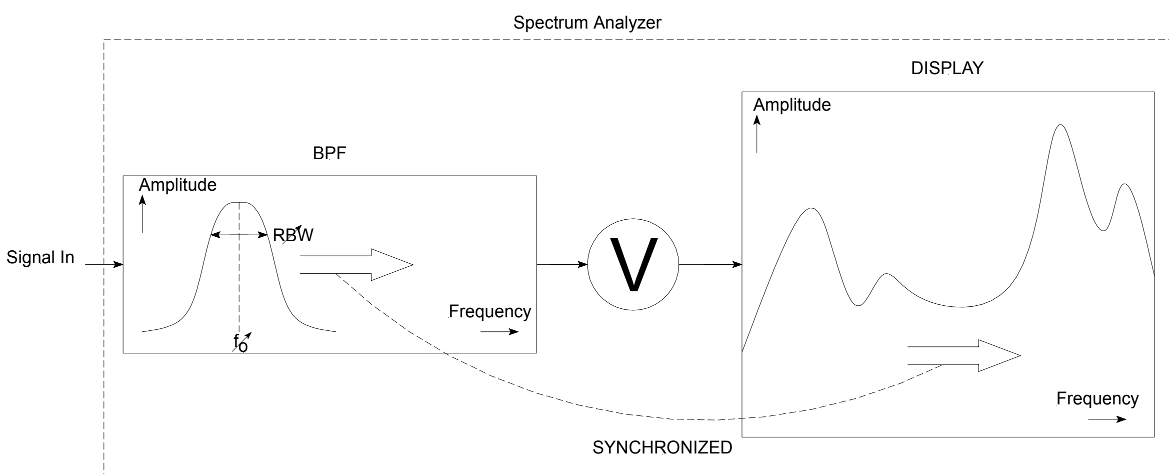
Spectrum Analyzer

There is only one type of analog spectrum analyzer available for use in the laboratories. It is the HP 3580A Spectrum Analyzer. This spectrum analyzer is limited in its maximum frequency—only 50 kHz. However, it has some nice features and is an excellent teaching aid in that once you understand how to operate this particular spectrum analyzer, you will know how to operate any other spectrum analyzer.

A spectrum analyzer, as the name suggests, is simply a tool that allows you to examine a signal in terms of its frequency components. That is, it displays signal amplitude as a function of frequency. Exactly how it does this is surprisingly easy to understand.

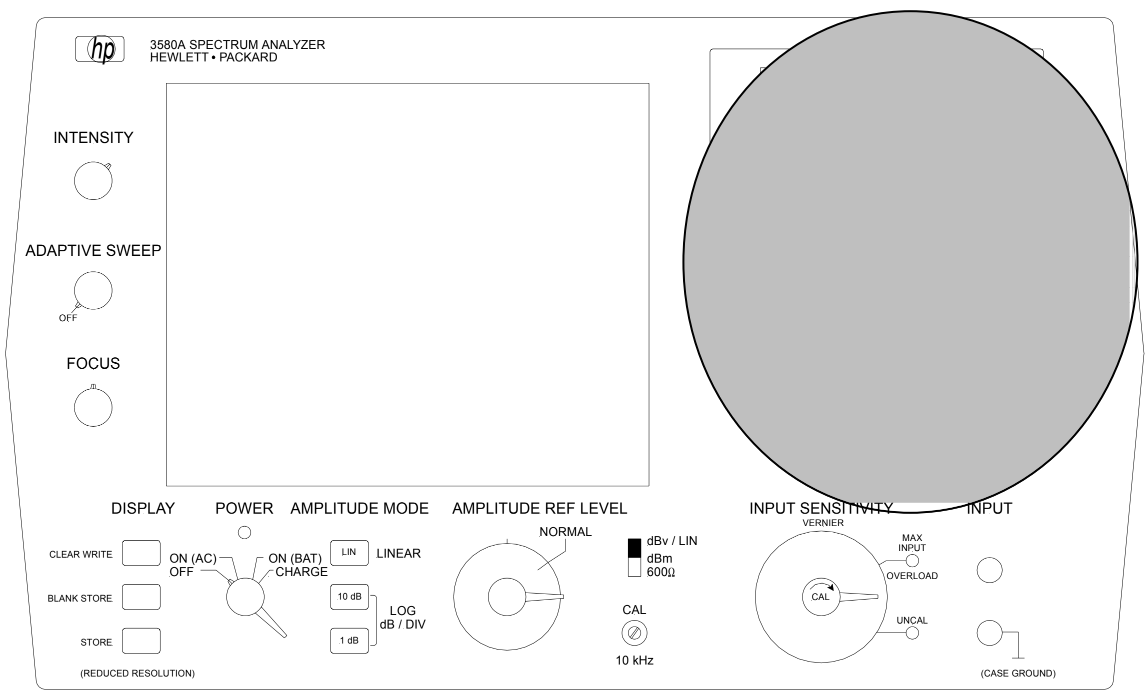
The illustration below is a very simplified block diagram of the electronics inside of a spectrum analyzer. The input signal passes through a bandpass filter (BPF), then through to a sensitive voltmeter which controls the level of the line displayed on the screen. The center frequency, f_o, of the BPF is continually swept from a low to a high frequency and the line sweep on the screen is synchronized with the BPF sweep. In this manner, the spectrum analyzer examines a tiny portion of the total spectrum at any given time, and thus yields a picture of the total or composite spectrum of the signal you are examining every time a sweep is performed.



Two more major qualities of the sweep are controllable: the resolution bandwidth (RBW) and the sweep time. The bandwidth of the BPF within the spectrum analyzer may be set to a variety of different values. This is referred to as the resolution bandwidth of the spectrum analyzer, as it dictates the minimum required frequency separation of two spectral components in order for it to just resolve two those two components. For argument's sake, say you set up two different signal generators to output sine waves with exactly the same peak-to-peak voltage. Assume that one is set to a frequency of 1.0 kHz and the other is set to 1.3 kHz. The outputs of these two signal generators are passed through a summing amplifier and then into the spectrum analyzer. If the resolution bandwidth were set to 300 Hz, you would just be able to resolve two peaks in the display. However, if the frequency of the second signal generator were reduced to 1.2 kHz, then you would only see one peak on the display—the spectrum analyzer wouldn't be able to resolve the two signals into two distinct peaks.

The sweep time of the HP 3580A may be set by the operator, but newer spectrum analyzers do not have this adjustment, as the sweep time is automatically set. As you can well imagine, sweeping a BPF in frequency while keeping its bandwidth constant is a difficult endeavour. However, the most important aspect is the signal power (energy) that gets passed by the BPF. If the RBW is set very narrow, then not much signal energy makes it through the BPF per unit time. Thus the displayed spectrum may not be a true representation of the actual spectrum if the sweep time is set too fast. There is, therefore, a tradeoff between the RBW setting and the sweep time. A narrow RBW is desirable because it reveals the most detail in the spectrum, but in order to maintain an accurate display, the sweep speed must be reduced to a very slow value. Thus, in spectrum analysis, we frequently set the RBW only as narrow as is necessary in order to facilitate a sweep speed that is as fast as possible.

HP 3580A Spectrum Analyzer



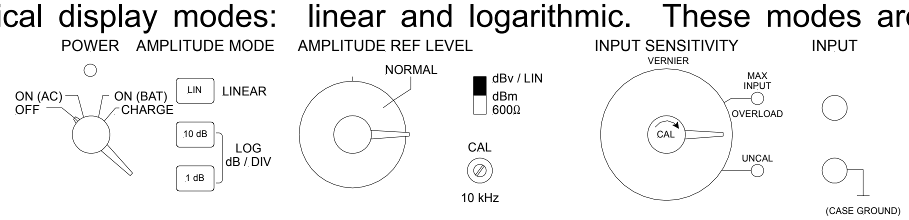
The controls on the front panel of the HP 3580A are well laid out and easy to find. The sweep controls (highlighted above) govern the frequency sweep characteristics of the instrument.

The display of the analyzer may be set to start or center modes, as indicated by the switch with STR and CTR above it. Depending on this switch, the LED display indicates either the start frequency in Hz, corresponding to the leftmost line on the display, or the center frequency in Hz, corresponding to the center line on the display. The adjust knobs (coarse/fine) to the right of the LED display control the start/center frequency. Not all of the HP 3580As have this LED readout; some have an analog start/center frequency readout. It doesn't matter what type you choose, as they both work equally well.

The SWEEP MODE dial should be set to REP (repetitive). At no point in the labs will you need to set the mode to anything but repetitive. The remaining three dials, RESOLUTION BANDWIDTH, FREQ SPAN/DIV, and SWEEP TIME/DIV all work in conjunction. As was mentioned earlier, selecting a narrow RBW will yield a more accurate spectrum, but the sweep speed will need to be slowed in order to maintain an accurate reading. If your selected sweep speed is too fast to maintain an accurate reading, the ADJUST indicator will light. Adjust the sweep speed to a slower value until the ADJUST indicator turns off. At that point, the display will be accurate.

The RESOLUTION BANDWIDTH dial has another control, DISPLAY SMOOTHING built into its knob. This control has three settings, and should be rotated fully counterclockwise to its minimum position. Display smoothing is also known as the video bandwidth on modern analyzers, and is, as the name suggests, a control that adjusts the smoothness of the displayed spectrum. You may think that the display smoothing should be set to its maximum setting all the time, but like the other frequency sweep controls, it also is tied into the sweep speed. At its maximum setting, the sweep speed must be set prohibitively slow to ensure an accurate display.

The amplitude controls are found along the bottom of the instrument. The analyzer has two vertical display modes: linear and logarithmic. These modes are selected by the AMPLITUDE MODE pushbuttons found just to the right of the power switch.



The UNCAL indicator light found to the right of the INPUT SENSITIVITY knob will light when the CAL adjust knob is not rotated fully clockwise. This means that the display of the analyzer is uncalibrated, and therefore inaccurate. Always rotate the CAL knob fully clockwise so that the UNCAL indicator stays off.

Before ever connecting an input signal to the analyzer, always adjust the INPUT SENSITIVITY control to its least sensitive setting. This means the fully counterclockwise position, minus one. The fully counterclockwise position is the CAL (calibrate) mode. This mode disconnects the front panel inputs from the analyzer, and internally connects a 10 kHz calibration signal, obviously for calibration purposes. This mode will be explained in detail later.

Once you have adjusted the INPUT SENSITIVITY control to its least sensitive setting and connected an input signal, start turning up the sensitivity (clockwise) while keeping a close watch on the MAX INPUT / OVERLOAD indicator light. The analyzer contains some very sensitive electronics which can be very easily damaged by large input signals, and if the MAX INPUT / OVERLOAD indicator lights, the input signals are too large (and potentially damaging). The INPUT SENSITIVITY control should then be turned down (counterclockwise) until the overload indicator goes off. Adjusting the INPUT SENSITIVITY in this manner ensures that the largest components in the spectrum are as large as possible in the display, without overloading (clipping).

Reading the vertical scale is frequently the source of the greatest confusion among students. If the LINEAR amplitude mode button is pushed in, the switch marked dBv/LIN / dBm 600Ω should be set to the dBv/LIN position. There is a white area behind the numbers on the INPUT SENSITIVITY knob. There are two sets of numbers, one in blue, the other black. In the linear mode, the top line of the display corresponds to an RMS voltage, and this voltage is indicated by the blue number currently highlighted on the INPUT SENITIVITY knob. The bottom line of the display corresponds to 0 V. For example, if the INPUT SENSITIVITY knob has been turned to its least sensitive scale, the analyzer is in the linear mode, and the AMPLITUDE REF LEVEL has been set to NORMAL (more on this control below), then 20 is highlighted. This means that the top line of the display corresponds to 20 V_{rms}. The middle line would then be 10 V_{rms}, and the bottom line 0 V. Since there are 10 vertical divisions, the vertical scale would be 2 V_{rms}/div.

There are two general logarithmic scales, selectable via the switch marked dBv/LIN / dBm 600Ω. In the dBv mode, the display is in decibels referenced to one volt rms. The level of a signal in dBV is given by the following formula:

$$\text{Signal Level (dBV)} = 20 \log (V_{rms}/1\ \text{V})$$

Where V_{rms} is the rms voltage of the signal. To convert signal levels in dBV to rms volts,

$$\text{Signal Level } (V_{rms}) = 10^{(\text{Signal level (dBV)}/20)}$$

In the dBm 600Ω mode, the display is in decibels referenced to a milliwatt for a 600Ω load. Note: you will require an external 600Ω load connected in parallel with the analyzer's input for this mode. For this reason the dBm 600Ω mode is not normally used.

If either logarithmic amplitude mode is selected (10 dB/div or 1 dB/div), then you refer to the highlighted black number on the INPUT SENSITIVITY knob. For example, if the INPUT SENSITIVITY knob has been turned to its least sensitive scale, the analyzer is in the 10 dB/div mode (dBv scale), and the AMPLITUDE REF LEVEL has been set to NORMAL, then +30 is highlighted. This means that the top line of the display corresponds to +30 dBV; the next line down would be +20 dBV and so on. The bottom line would correspond to – 70 dBV.

The greatest accuracy in reading the level of a component is achieved when the component is as large as possible without clipping or running off the top of the display. When you are examining spectra that have both large and small components, it is desirable to make the small components as large as possible in order to accurately measure them, as mentioned above. However, if you were to adjust the INPUT SENSITIVITY to do so, chances are that you would overload the analyzer. By adjusting the AMPLITUDE REF LEVEL dial, you can effectively do just that, without the danger of overloading the analyzer. The AMPLITUDE REF LEVEL dial is connected to the white area on the INPUT SENSITIVITY knob. Turning the AMPLITUDE REF LEVEL changes the location of the white area, and thus the scale.

The INTENSITY and FOCUS controls do as you expect. The ADAPTIVE SWEEP knob should always be set to the OFF position. The three DISPLAY pushbuttons at the bottom left side of the front panel are quite self-explanatory. When the STORE button is pushed in, a snapshot of the present display will be stored and continually redisplayed, even if the input changes or the settings on the analyzer are changed. If the BLANK STORE button is now pushed in, the stored waveform will not be displayed; it is, however, still stored. The CLEAR WRITE button acts as a reset/erase for the display.

The analyzer has a precision frequency reference within it, and this reference is not accurate/reliable until the analyzer has a chance to warm up. Usually 15 – 30 minutes is sufficient. Once the analyzer is warmed up, you should **ALWAYS** check its calibration. This calibration step is necessary to ensure that the analyzer is accurately measuring both frequency and amplitude.

By selecting CAL on the INPUT SENSITIVITY knob, a 10 kHz internal reference is internally connected to the analyzer's input. See the amplitude calibration procedure for details. Select the RESOLUTION BANDWIDTH to be used and calibrate. Recalibrate if another resolution bandwidth is selected. You should see a large spike at 10 kHz, and its amplitude should be such that it just touches the top grid line on the display.

When you adjust the start/center frequency, the LED readout takes some time to update, depending on the current sweep time/div setting. The LED is updated only once per sweep, and trying to set the start/center frequency can be quite frustrating because of this delay. To adjust the start/center frequency and have the LED readout update immediately, press and hold the CLEAR WRITE button while you are making the adjustments.

Amplitude Calibration Procedure

For operation on the 10Hz, 30Hz, 100Hz, or 300Hz resolution bandwidth.

(a) Turn the instrument on and allow 20 minutes for warm up.

(b) Set the 3580A controls as follows:

Display……………………………………………………Store and Blank Store **out**
Amplitude Mode…………………………………………………Log 10dB/division
Amplitude Ref Level……………………………………………………………Normal
dBV / Lin – dBm Switch……………………………………………………dBV / Linear
Input Sensitivity…………………………………………………………………..Cal
Vernier…………………………………………………………....Cal (Fully CW)
Frequency……………………………………………………………………10 kHz
Start CTR………………………………………………………………centre (CTR)
Bandwidth……………………………....10 Hz – 300 Hz (resolution to be used)
Display Smoothing……………………………………………………………..Min
Freq. Span / Div……………………………………see Amplitude Calibration Table
Sweep Time / Div…………………………………..see Amplitude Calibration Table
Sweep Mode…………………………………………………………repetitive (REP)

(c) Adjust the front panel 10 kHz CAL potentiometer so that the peak of the 10 kHz signal is exactly at the top reference line.

(d) Set the Amplitude Mode to Log 1dB/div. Repeat step (c).

(e) Set the Amplitude Mode to Log 10dB/div. Repeat step (c).

(f) Set the Amplitude Mode to Log 1dB/div. Repeat step (c).

Amplitude Calibration Table

Bandwidth settings	Freq. Span / Div	Sweep Time / Div
10 Hz	20 Hz	0.5 sec
30 Hz	0.1 kHz	0.2 sec
100 Hz	0.5 kHz	0.1 sec
300 Hz	1 kHz	0.02 sec

Printing the Display

The HP 3580A is an analog spectrum analyzer and cannot directly print to the printers available in the laboratories. However, you can hook the analyzer up to an Oscilloscope, and print the spectra from there.

On the back of the analyzer are a number of connectors. The ones marked RECORDER X-AXIS and Y-AXIS are the ones you will need. These outputs are meant for printing to an old-fashioned pen plotter.

The oscilloscope should have its two X and Y input channels (channels 1 and 2 respectively) set to dc coupling, and 500mV/div. Position each channel's ground level to approximately the middle of the screen. The X-AXIS output on the analyzer goes to the X channel on the scope, and similarly the Y-AXIS output gets connected to the Y channel. Once you have made the necessary connections, turn on the X vs. Y display mode of the oscilloscope.

You should see a dot moving across the Scope screen. Set the Analyzer's Sweep Mode knob to MAN for manual. Use the Sweep Mode vernier knob to adjust the dot on the analyzer's display to the center vertical graticule. Use the Scope X channel position knob to move the dot left or right, and use the Scope Y channel position knob to move it up or down. Your goal is to place the dot on the center vertical graticule of the scope display to resemble the dot on the analyzer's display. Once this is done, set the Sweep Mode knob to SING for single sweep.

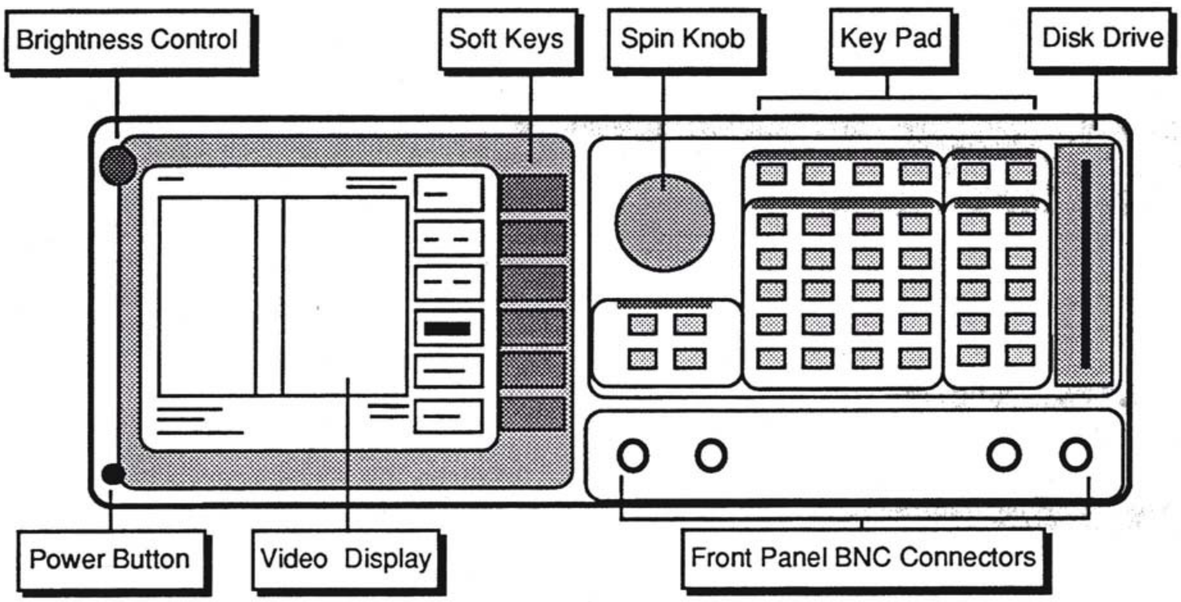
Once this has been accomplished, press the Auto-store button (HP Scopes) or set the display persistence to infinite (some of the other scopes). Press and release the Display Clear Write button, on the Analyzer, to activate a single display sweep. Once the spectrum analyzer's screen has been traced by the scope, press the Scope's stop button and print the waveform.

Amplitude Response of Two-Port Networks

There is an output on the back of the spectrum analyzer called the TRACKING OSC (oscillator) OUT, along with a LEVEL adjust knob. The output is a sine wave with a variable swept frequency that is synchronized to, or tracks the frequency being analyzed across the screen at any point in time. This is used to make a measurement of the frequency response of a two-port network (i.e. a filter, an amplifier, etc.). The output impedance of the TRACKING OSC OUT is 600 Ω and not the standard 50 Ω found in all signal generators. For this reason, a buffer amplifier (a voltage follower) should be employed to isolate the tracking oscillator from the network you are testing to avoid circuit loading. Connect the TRACKING OSC OUT through a voltage follower to the input of the spectrum analyzer. The TRACKING OSC LEVEL knob is adjusted for a reference level of aprox. - 40 dBv on the front display. All measurements are referenced from this level. Connect the output of the voltage follower to the input of your network. The output of your network is then connected to the input of the analyzer. In one simple step, this allows you to measure the amplitude response of the network as a function of frequency. This is opposed to the long and arduous alternative method whereby you connect a signal generator to the network and monitor the input and output levels of the waveforms with an oscilloscope as you select frequencies.

SR770 FFT Network Analyzer

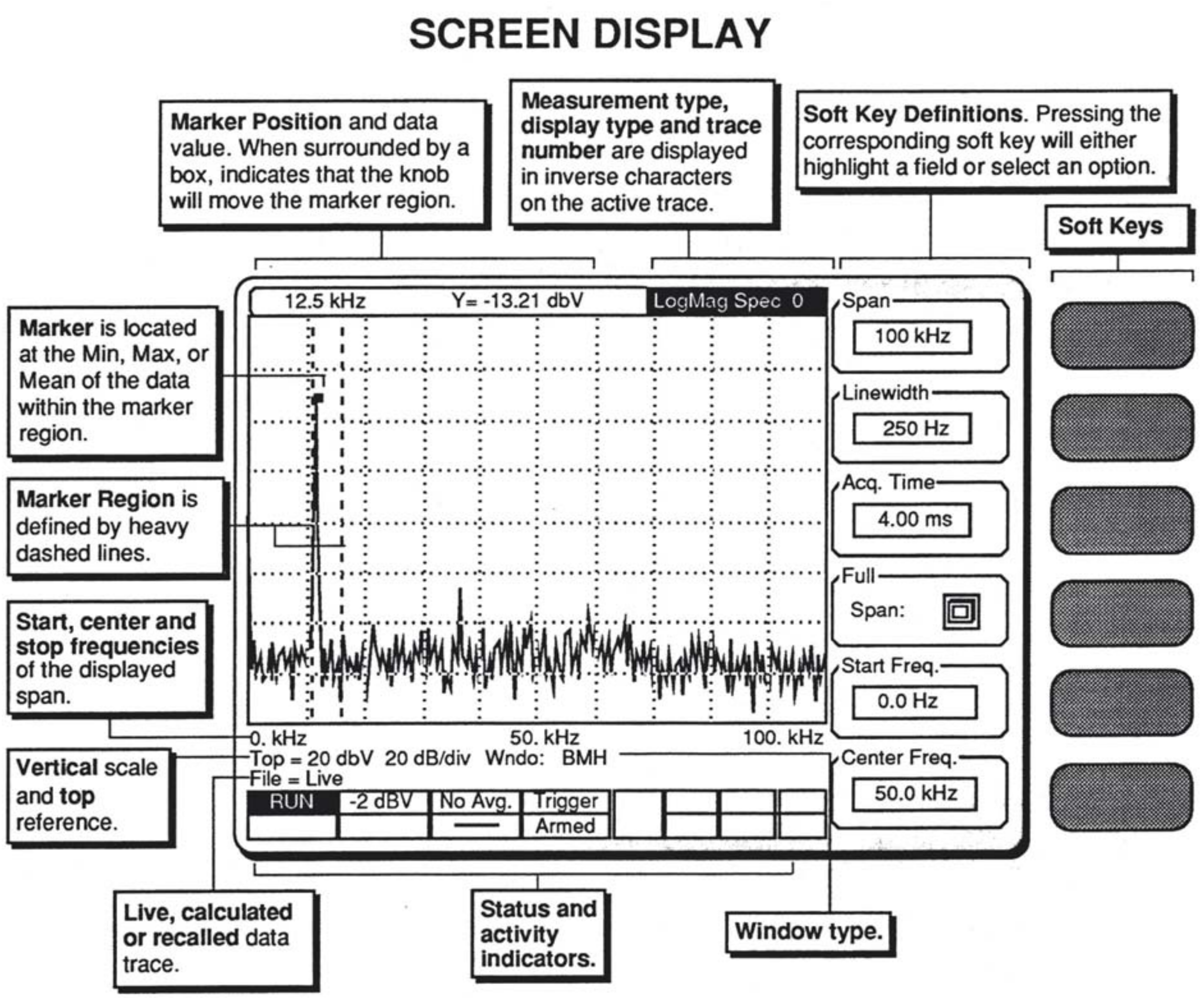
FRONT PANEL OVERVIEW



(Standford Research Systems, 2000)

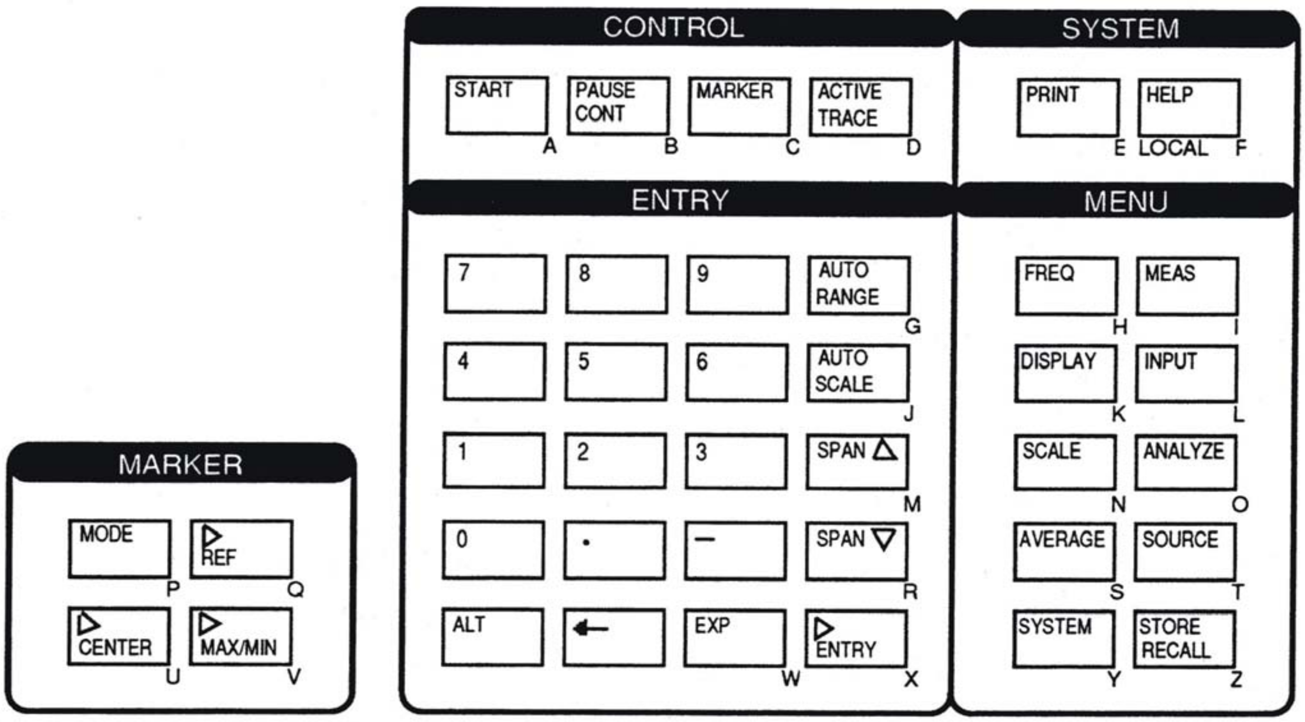
A FFT spectrum analyzer takes a time domain input signal, samples it and digitalizes it (analog/digital converter). The digital data samples (time record) are converted to the frequency spectrum using the fast fourier transform. The maximum frequency span of the SR770 is 0Hz to 100KHz. This FFT processor displays 400 frequency points (bins). It uses a 512 point time record. At full span (0 to 100KHz), the bins are 250 Hz apart. The bins are at 250Hz, 500Hz and so on. The resolution or linewidth is 250Hz. At a frequency span of 50KHz the bins are 125Hz apart. The bandwidth (frequency span) is controlled by digitally filtering the data samples. The digital filter is only capable of base-band measurements (frequency spans starting at DC). Heterodyning allows the span to start at frequencies other than base-band. Heterodyning multiplies the signal by a sine wave. The frequency span is shifted by the frequency of the sine wave. This shifts the frequency span so that it starts at DC. This allows the analyzer to display spans which start at frequencies other than DC. Spectral components that have a negative magnitude are folded around zero and appear as a positive magnitude.

The time record, which can be displayed by the measure menu, is not a true representation of the input signal. It is the input to the FFT processor. The time record has been digitally filtered and maybe heterodyned before the FFT processor receives it. Real time bandwidth is the largest frequency span whose time record does not exceed the time it takes the FFT processor to calculate the spectrum. With narrow spans, where the time record is long then the processing time, the processor would calculate one FFT per time record and wait till the next time record is completed. The update would be slow. With overlap processing, data from the previous time record and the current time record is used to calculate the next FFT. The overlap is a percentage of the time record. No overlap is 0% and 99.8% reuses 511 out of 512 samples. The SR700 uses the maximum amount of overlap allowed. This varies with the span. The analyzer uses overlap processing in the continuous trigger mode only. No overlap is allowed, on spans of 25KHz and over. The average menu may be used to enter a smaller overlap.



(Standford Research Systems, 2000)

KEYPAD



(Standford Reasearch Systems, 2000)

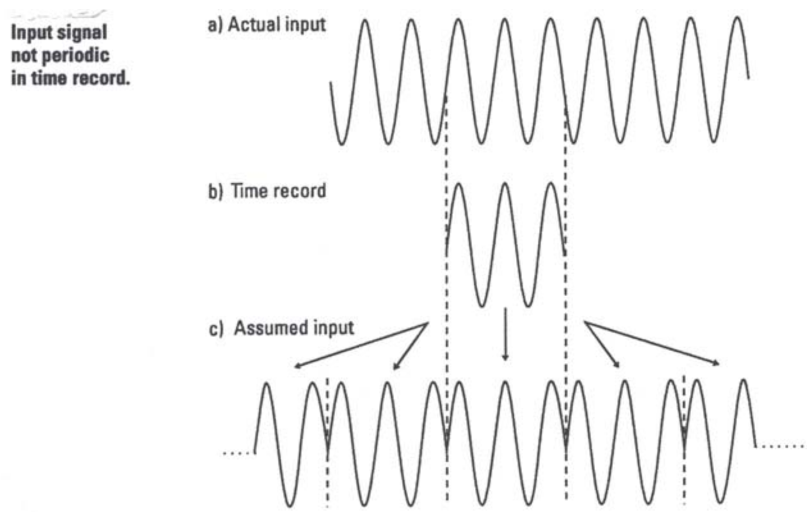
To reset the analyzer, to the default settings, hold down the **<** key when the power is turned on. Continue holding the key down until the power-on tests are completed. Wait 30 seconds between switching power off and on with any cathode ray tube. Do not set the brightness higher then necessary.

The **Auto Range** key is used to set the attenuation on the input signal so that it does not overload the analyzer input. The **Auto Range** key toggles the input range mode between auto and manual. In manual mode, the input range is set in the **Input** menu. The auto mode will display the input level indicator, on the display, in inverse characters.

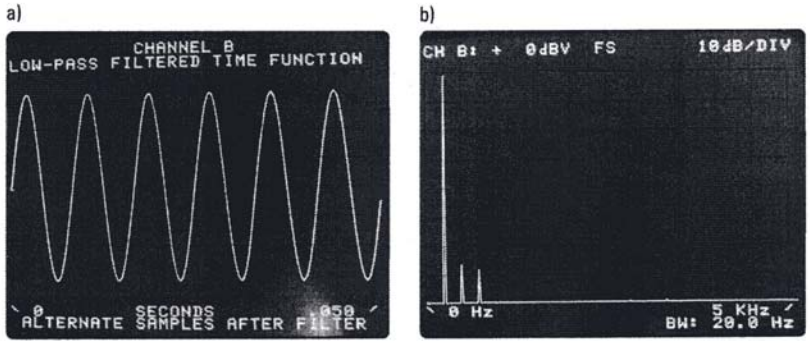
The frequency span is set in the **Frequency** menu. Pressing the **Start Freq** or **Center Freq,** before the span is adjusted, locks these frequencies in. The **Measure** menu is used to set the type of measurement, display, units and window.

Windowing

The FFT algorithm is based upon the signal repeated throughout time. The time record, which is formed from the input signal, must be periodic.

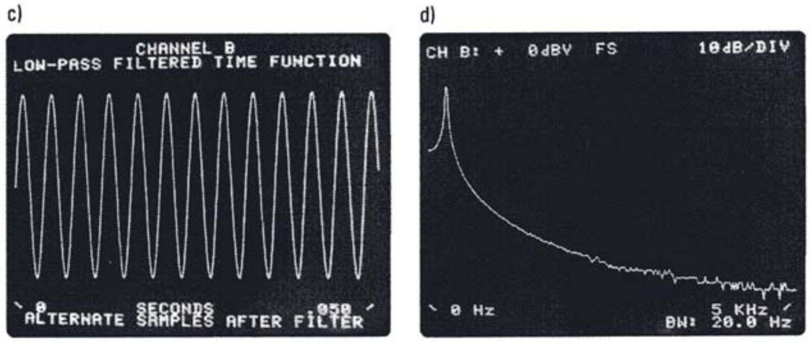


a) b)



a) & b) Sine wave periodic in time record

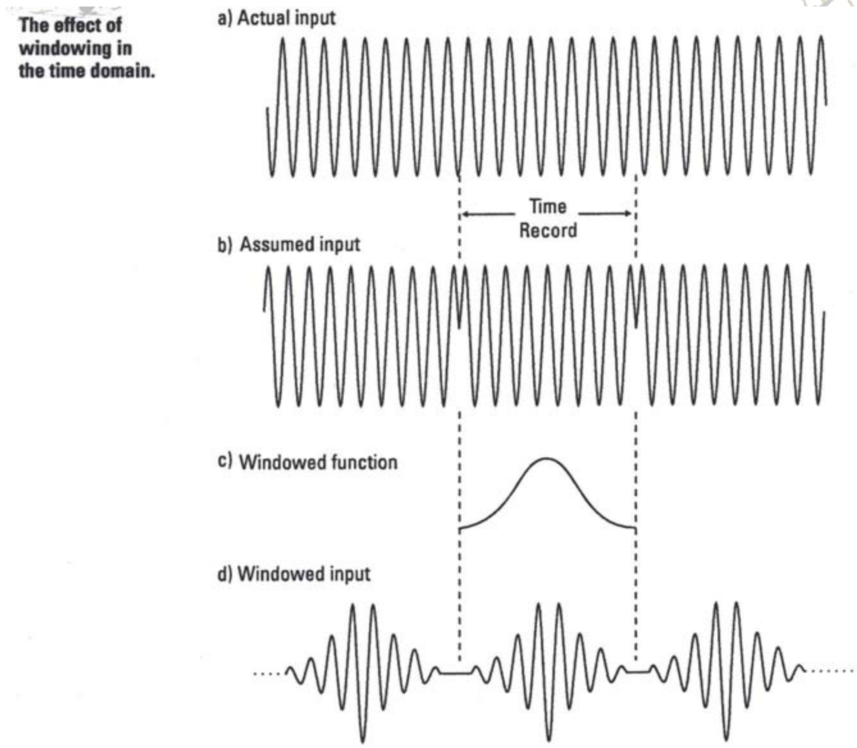
c) d)



c) & d) Sine wave not periodic in time record

(Agilent Technologies, 2000)

Energy is smeared throughout the frequency spectrum if the signal is not periodic. Windowing solves this problem. Windowing functions taper off to zero at the start and the end.



(Agilent Technologies, 2000)

The **Window** submenu is found in the **Measure** menu. The **Uniform** window is basically no windowing. It is used for pulses and transients which are shorter then the time record. The **Flattop** window is used for magnitude measurements of continuous signals. The **Hanning** window is used for frequency measurements of continuous signals. The **BMH** (Blackman-Harris) window has the best selectivity because of it's narrow mainlobe and a fast roll-off.

Note: A input signal is at 10.1 KHz. The analyzer displays the peak at 10 KHz. This is because the FFT only results in 400 discrete frequency bins. The signal peak is always wider than with no windowing. This reduces the selectivity of the spectrum. Signals that are not at exact bin frequencies will have a reduced amplitude. This is because window functions attenuate the amplitude between bins.

The **Input** menu is used to configurate the input. The **Grounding** key selects the shield grounding. In the **Float** mode, the shields and chassis ground are connected by a 1 meg ohm resister. In the **Ground** mode, the shields and chassis ground are connected by a 50 ohm resister. Do not exceed 3V on the shields in the **Ground** mode. The impedance between the centre connector and the shield is 1 meg ohm. In general, use input **A** and the **Ground** mode for single ended measurements. When the **Input Source** is set to **A-B** (differential), the **Ground** mode is set automatically. In **A-B** configuration the centre pins of **A** and **B** are connected to the circuit under test. The shields are not connected to the circuit under test and do not carry a signal. They act as shields.

The **Input** menu contains the **Auto Offset** calibration function. The calibration takes about 10 seconds. The inputs are internally grounded and the DC offsets of the amplifier are taken into account. The DC frequency bin will be minimized. Turn the **Auto Offset** off, when making very narrow span measurements or using the source.

The **Input** menu also contains the **Trigger** mode. In the **Cont** mode the analyzer takes time records continuously. This is the default mode. The time records are triggered by the input signal with the **Int** (internal) mode. With **Ext** or **TTL**, the time record is triggered from the external trigger input on the front panel. **Src** (source) mode is used with the sine, two tone, or chirp sources. The source is a built in function generator. In the **Src** mode the spectrum is calculated with no overlap and no trigger circuits. Signals of the **Source,** that are identical in each time record, will have a stable phase and appear triggered. The source will have a stable phase if the frequencies are centered on the bins. The phase of the source will be arbitrary. The SR770's source uses the same clock as the input record. A external generator will not be in sync with the analyzer's clock and will drift off the bin frequency. The phase of the source will change with the span, source, or auto offset calibration.

The **Scale** menu is used to change the x and y parameters of the display. Activating the **Y/Div** key will lock this parameter in when the **Top Ref** or **Bottom Ref** are adjusted. **Expand X** (zoom) allows detail expansion of the spectrum, about the marker postion, without decreasing the span and thus increasing the acquisition time.

The **Average** menu selects the number of averages, type of averages, averaging mode and the amount of overlap. The **Average Type** function selects **RMS, Vector,** or **Peak Hold**. **RMS** (power averaging) averages the magnitude of the spectra only but does not reduce the noise floor. **Vector** averages the complex spectrum. This will reduce the noise floor for random signals as they are not phase coherent between time records. **Vector** averaging uses a trigger. The input signal must be periodic and in phase with the trigger. This will add in phase the real and imaginary parts of the signal. Otherwise, they will cancel randomly. If the signal is not an exact bin frequency, the signal magnitude will be reduced. The **Average Mode** key selects **Linear** or **Exponential** averaging. **Linear** averaging is not continuous. The analyzer will stop acquisition once the average function is complete. **Exponential** is continuous (live). A large number of averages, in the exponential mode, will not capture any changes in the signal.

The **SOURCE** menu selects the output waveform. The **Configure Source** submenu sets the parameters. The **2-Tone** waveform is the sum of two pure sine waves for intermodulation distortion tests.

The **Chirp** source provides an equal amplitude sine wave at each **bin** of the span. The phases of the sine waves are set so that they do not add in phase. This source is used to measure transfer functions (frequency response). The waveform is periodic over the time record and does not require windowing. Use the **Uniform** window and the **Src** (source) trigger. Turn the **Auto Offset** off in the input menu. The source is digitally synthesized and has an output filter. The ripple of this filter appears at the output. **Source Cal** compensates for the output ripple by adjusting the input calibrations. The signal at the source output is not adjusted. If a device is inserted between the source and the input, the amplitude frequency response of the device will be displayed. The **Auto Phase** key performs the auto phase function. With **Src** (source) trigger, the phases of the sine waves of the source are stable but random. A calibrated source phase curve is required to measure the phase of a device under test. The auto phase function measure the current phase spectrum of the source and then subtractes it from the next phase spectrum to remove the phase from the source. With **Auto Phase**, the phase spectrum will be 0 degrees across the span. If a device is inserted between the source and the input, the phase spectrum will be the phase response curve of the device under test. **Auto Phase** is turned off whenever the span or source type is changed.

NOTE: A inherent problem exists when a frequency response is done with a small linewidth. Errors may occur if the start frequency is not at zero or **Center** (on the **marker** keypad) is used. Detail expansion of the frequency span can be done using **Expand X** (zoom) with no errors. Ensure the frequency of interest is at the center of a bin. It is always best to know the expected output. An analog spectrum analyzer with a sine source is a more accurate analyzer to use for a frequency response.

Frequency Response Summary

- Use **Chirp** source.
- **Uniform** window.
- Source **Cal**.
- Trigger **Src**.
- **Auto Offset** off (Input menu).
- **Auto Phase** optional.
- Start frequency at zero.
- Do not use **Centre** on Marker keypad.
- Place Marker on centre frequency and use **Expand X**.

Printing the Display

Connect a HP Thinkjet Centronics Port Printer to the **Print Port** on the back of the analyzer. Enter the **System** menu on the **Menu** keypad and then the **Print** submenu using the soft keys. **Printer Type** select **HP**. Press **Print** on the **System** keypad.

Save to 3.5 Disc.

Enter the **System** menu on the **Menu** keypad and then the **Print** submenu using the soft keys. **Printer Type** select **File**. Press **Print** on the **System** keypad.

References

Standford Research Systems. (2000). “SR700 Network Analyzer Operating Manual and Programming Reference. Revision: 1.4 (10/2000)”. Sunnyvale CA U.S.A. :Author.

Agilent Technologies. (2000). “The Fundamentals of Signal Analysis, Application Note: 243”, California, U.S.A. : Author.