Interactive Modulation Analyzer Control

by Paul J. Lingane

THE MICROPROCESSOR-BASED CONTROLLER in the 8901A Modulation Analyzer interacts closely with the hardware subsections of the instrument to create a unified system. The controller also interacts with the user, both through the front panel and by responding to the RF signal applied to the input. Control in the instrument takes place at several levels.

At the functional block level the controller uses various circuits as separate instruments: the RF level detector as a power meter, the local oscillator as a signal generator, and the analog-to-digital converter as a voltmeter. The frequency counter, IF section, and audio section are blocks that can be manipulated in various ways to tune to a signal and make a measurement.

The microprocessor is also used as a circuit component. Half of the hardware registers and associated circuits in the frequency counter were replaced by software registers. The local oscillator relies on the speed of the microprocessor to control its phase-locked loops; manual control is impossible with the block diagram that was selected.

The controller makes it possible to transfer some complexity of hardware into complexity of software. This tends to improve reliability and flexibility in the use of circuits, allowing more to be done with the same hardware. The local oscillator was designed with that in mind. Also, software for linearization of nonlinear detectors and predistortion of control voltages to the VCO and VCXO allow reductions in the cost and complexity of that hardware.

This close interaction between the controller and the hardware impacts the service strategy, as traditional service procedures are not always effective at identifying problems. The action of the controller can multiply the effect of a circuit failure so it may appear as a collection of symptoms that superficially seem unrelated. I will say more about this later in this article.

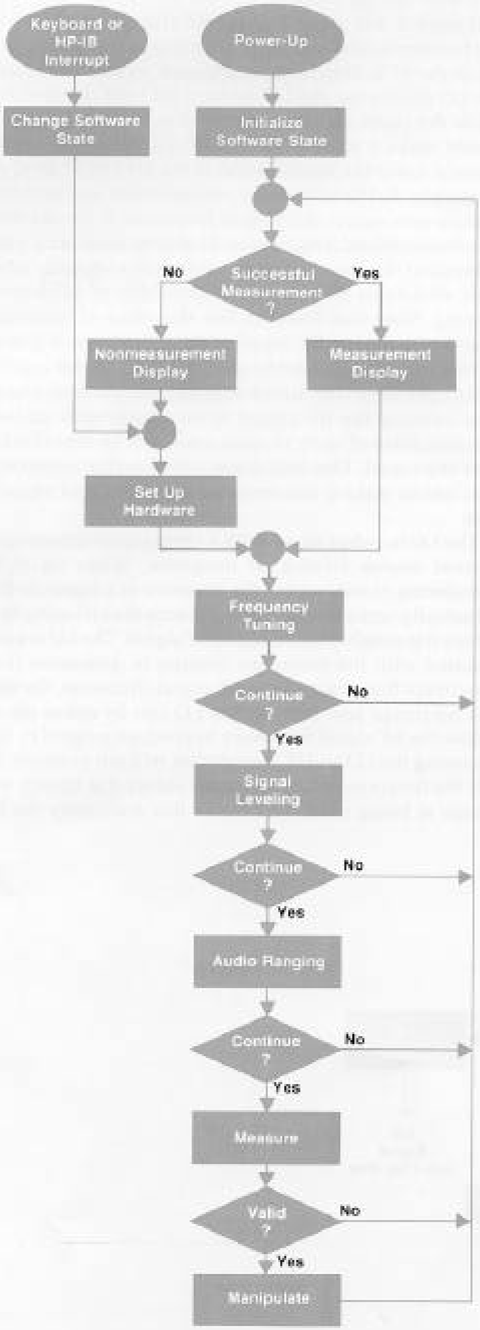


Fig. 1. *8901A software supervisory loop is continuously traversed by the microprocessor-based controller. A measurement is made near the bottom only if all preceding tests are passed in immediate succession.*

Software Structure

An important maxim in the design philosophy of the modulation analyzer was, "Don't mislead the user." Both the software structure and a system of error messages were designed to instill confidence in the measurement.

The 8901A software is structured in a form that we have dubbed the supervisor (see Fig. 1). It is a loop that is continuously traversed, with the measurement made near the end, after checks for proper frequency tuning, proper RF and IF level, and correct audio range. Arithmetic manipulation (e.g. for the ratio function) follows the measurement, and the program then loops back up to display.

The frequency, level, and audio blocks verify that the 8901A is adjusted to make an accurate measurement. A measurement is not made until all of the tests are passed in immediate succesion. Let us say, for example, that the RF input level has changed. The signal leveling block therefore reduces the RF attenuation to boost the IF level to an acceptable value. The decision after this block forces the program back to the top of the supervisor, bypassing the measurement for that loop. This reduces interaction between the blocks and aids identification of the nature of the input signal change.

In the example above, perhaps the real situation was that an octave bandswitch was changed on the RF signal generator under test, so now the second harmonic of the desired signal has been tuned into the IF of the 8901A. Since it is lower in level than the fundamental the leveling block boosts the IF level. But the real problem is that the LO is now improperly tuned to the fundamental. Looping back before a new measurement is made gives the frequency tuning block a chance to correct the tuning.

The software interface with the hardware makes use of two concepts called software state and hardware state. The software state is located in 22 bytes of RAM and totally describes the state of the instrument. On power-up, the initialization procedure loads the software state from ROM. Keyboard and HP-IB entry routines modify only the software state and do not affect hardware immediately. The setup block in the supervisor is where the hardware state is made to conform with the software state. Setup is not the only place where hardware is affected; the frequency tuning, leveling, audio ranging, and measurement blocks manipulate the hardware as well.

The keyboard and HP-IB can be thought of as a medium through which the user requests a certain instrument setup. In fact, the actual instrument setup is guaranteed to conform to the keyboard request only at the moment a measurement is taken. The controller may change the instrument hardware at other times to optimize its tuning, leveling, and ranging functions.

In a normal stable measurement cycle the program takes the measurement display branch at the top of the supervisor and so avoids the time overhead associated with the setup block. However, if the program loops back before taking a measurement, or if an error condition exists, the nonmeasurement display branch will be traversed, thus lighting an appropriate display and going through the setup block. This refreshing of the hardware state when error conditions are sensed contributes to the robustness of the software structure.

Tuning to a Signal

As a measuring instrument the 8901A must be able to cope with input signals whose nature is unknown, except that they must be within the specified frequency, power, and modulation ranges. The controller manipulates the various subsections of the instrument to first understand the nature of the input signal and then to respond effectively to it by changing the setup to make the measurement. An example is the frequency tuning block of the supervisor.

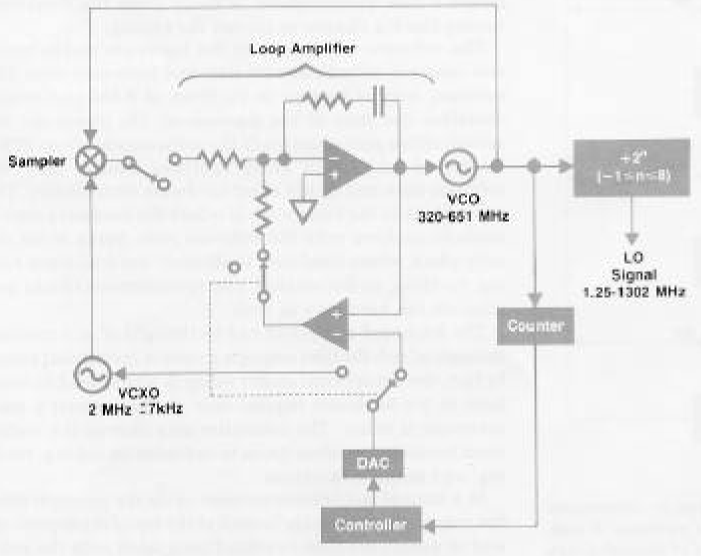
The user simply wants to apply a signal and make a measurement. From the point of view of the modulation analyzer, however, it may be presented with a complex RF spectrum consisting of an RF signal with its harmonics, perhaps drifting in frequency and being modulated with a complex waveform at high FM deviations and large amounts of AM. The modulation analyzer must accurately tune the local oscillator to the signal, range the RF and audio levels, and make a fully settled and stable measurement within a second or two after a signal is applied.

The 8901A is basically an accurately calibrated radio receiver that tunes to an RF signal by mixing a single local oscillator (LO) signal with the RF to produce an intermediate frequency (IF) signal that is demodulated and analyzed. To locate a signal automatically, the local oscillator is quickly swept throughout the entire frequency range of the instrument, looking for a signal to appear in the IF section. Since the LO is a square wave, rich with its own harmonics, it is swept down from high to low frequencies so that the fundamental of the LO will be the first LO signal to mix with the RF signal.

If there is AM present on the RF signal it is possible that the fundamental of the LO will sweep past the input signal while the RF is deep in the AM trough, so that a harmonic of the LO (following the LO down a bit later in time) might catch the input signal as it comes out of the trough. This would make it appear that the RF signal is at a lower frequency, since the fundamental of the LO would be at a low frequency. So the LO is swept several times, and each time it finds a new signal at a higher frequency it throws out the previously found frequencies. This continues until a signal is found at the same frequency during five separate sweeps. This effectively eliminates the possiblity of LO harmonic mixing. Note that this also has the effect of favoring the highest-frequency RF signal if more than one is present.

To avoid the possibility that the LO's sweep repetition rate might be synchronized with the amplitude modulation rate, causing the RF signal to be consistently missed, a variable delay of up to 10 ms is used after sweeps that fail to find any signal. This introduces jitter into the sweep repetition rate to make it uncorrelated with the input signal AM rate.

The LO is swept down with a ramp signal generated by a current source driving an integrator. When an IF level monitoring circuit senses the presence of a signal in the IF, it instantly turns off the current source thus freezing the LO where it is roughly tuned to the RF signal. The LO is quickly counted with the frequency counter to determine the approximate frequency of the RF signal. However, the 8901A has no image rejection, so the LO can be either above or below the RF signal frequency to produce a signal in the IF. Knowing the LO and IF frequencies will not uniquely identify the frequency of an RF signal unless it is known which image is being used. To resolve this ambiguity the LO is



Switches shown connected to pretune the VCO with the DAC

Fig. 2. *8901A local oscillator was developed using the controller as an essential element.*

tuned to the frequency where an IF signal appeared, then it is stepped up in frequency while monitoring the IF level until it sees the IF signal level moving down the skirt of the IF low-pass filter. The LO at this point must be above the RF signal frequency, thus identifying the image.

The RF signal frequency is known by accurately counting the LO and IF. This count lasts over 100 ms to gain sufficient resolution, so a drifting RF signal may move out of the IF passband during the count. To avoid this the LO is configured for track mode during the count, so it will always remain tuned to the signal.

Now that a signal has been found and accurately identified as to frequency, call it f, it is still possible that it is actually a harmonic of the desired signal. So the controller directs the LO to tune to f/3 and then looks for the presence of a signal that is higher in amplitude than the signal at f. If this happens then the signal at f is assumed to be the third harmonic of the applied input signal, so the modulation analyzer will tune to f/3 as the fundamental. If the signal at f is not the third harmonic, a similar check is made at f/2 to see if the second harmonic is involved.

Once the fundamental of the input signal is identified, the LO can be properly tuned and the rest of the instrument initialized and set up to take the desired measurement.

This simplified description of one algorithm in the 8901A illustrates the close interaction of the controller with the various subsections of the instrument at the functional block level.

Control of the Local Oscillator

The controller is also closely tied with the hardware at a circuit level. As an example the block diagram of the local oscillator was developed with the controller as an essential element (see Fig. 2).

When configured for low-noise, fixed-frequency operation, the heart of the local oscillator consists of a high-frequency voltage-controlled octave oscillator (VCO) that is locked to a harmonic of a low-noise voltage-controlled crystal oscillator (VCXO). An internal frequency counter is available to monitor the frequency of the VCO. The specification of the two oscillators calls for only a modest degree of linearity between the tune voltage input and the output frequency. This is because the controller can tune the two oscillators by adjusting the voltage control until exactly the desired frequency is attained.

The first step in the tuning procedure is to pretune the high-frequency VCO to approximately the desired frequency. Then the tuning DAC (digital-to-analog converter) is disconnected from the loop amplifier and connected to the low-frequency VCXO, which is then adjusted near the bottom of its range. Meanwhile the VCO has remained where it was because of the sample-and-hold nature of the integrator in the loop amplifier. Now the sampler can be connected to the loop amplifier, and a dc offset voltage at the output of the sampler drives the VCO down in frequency until it acquires lock on the nearest harmonic of the VCXO. The VCXO can then be adjusted to fine-tune the VCO to the proper frequency. Binary dividers and a doubler convert the VCO signal to the desired octave in the 1.25-to-1302-MHz range.

Frequency Counter

The frequency counter chain is partitioned into two parts, roughly four decades of higher-speed counters in hardware and about five decades of lower-speed counters emulated by the controller. A 10-MHz crystal oscillator is divided down to 6.25 kHz to provide the basic timing signal monitored by the microprocessor. The controller times a count by keeping track of this 6.25-kHz time base while accumulating frequency counts at rates up to 3 kHz. When sufficient time has passed to attain the frequency resolution desired, the controller turns off the counter gate, and reads the contents of the hardware decades. With this count and the count accumulated in the software registers, the microprocessor then calculates the frequency of the signal.

Implications for Service

The close interaction between hardware and software in the 8901A has definite implications for the use and servicing of the instrument. Service special functions were developed that can be used as service tools to diagnose problems. Some self-tests are available to check for certain failure modes. Since it is not possible to predict all types of failures, general-purpose software routines were developed that can be used in a variety of situations. One of these is a direct control special function that is called from the keyboard. It can read or write data to any instrument hardware location that is controlled by the microprocessor. A service person can use this to operate instrument circuits manually to check their performance.

A special class of error displays called service errors is available. When enabled by a service technician with a special function, they can reveal information about the internal operation of the instrument. Thus, for example, if the demodulated output is periodically being blanked, enabling service errors may result in an "Error 72" display. This would indicate that the audio overload protection circuit is being tripped.

The local oscillator section required particular attention. To lock the low-noise loop a series of switch openings and closings and DAC movements must be performed within an 8-ms interval. Since a service technician couldn't hope to duplicate this procedure manually, a series of self-tests concentrating on the LO is of value in testing gross operation of the circuit. These can be called from the keyboard,

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with results displayed on the front panel.

Some checks are automatically performed at power-up, with results flashed on four LEDs located within the instrument on the controller board. These include the LO tests just mentioned, as well as checks on the operation of the ROM and RAM of the controller, the internal instrument bus, the front panel, the keyboard, and the frequency counter. Signature analysis is also used in troubleshooting much of the digital hardware.

A clear line is drawn between service special functions and normal instrument operation. When most service special functions are used, normal instrument functions are suspended. When the service special function mode is left to resume normal measurements, all effects of the service functions on hardware are lost. As an example, a direct control special function can be used to activate a particular RF attenuator to check its operation. But once normal measurements are resumed the attenuator setting will revert back to what it was before the service special function was invoked.