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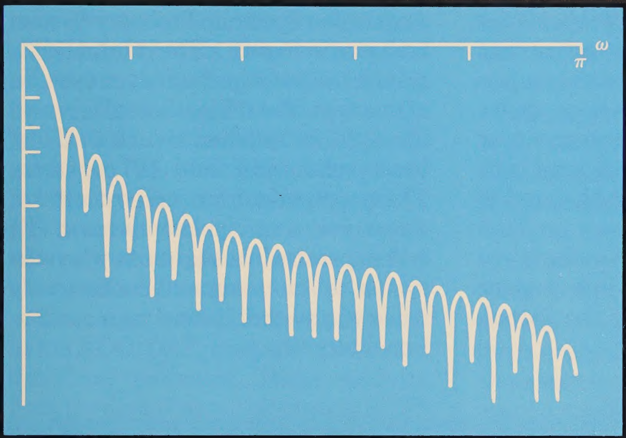
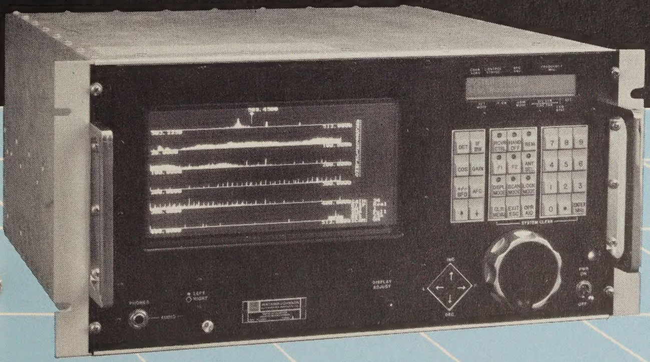
Rapid Broadband Signal Acquisition





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Tech-notes

Introduction

Pursuit of an effective means for signal reception over wide bandwidths while retaining sensitivity, high dynamic range, and narrow bandwidths has led the CET Division of Watkins-Johnson to the application of advanced rapid acquisition spectrum processing techniques. Previous papers on this subject have decscribed the range of solutions available to the rf side of this problem and have shown why the superhetrodyne receiver offers advantages over tuned rf, compressive, and other methods of signal detection.

For the detection and processing of newer-generation communications signals *with sufficiently high probabilities of intercept,* one needs the sensitivity associated with the classical superhetrodyne receiver as well as faster scanning rates over wider segments of the rf spectrum. Closely associated with these primary objectives is the need to be able to characterize large portions of the spectrum of interest so that they can be visually described independent of and without affecting the signal-acquisition process.

In developing an approach capable of answering these needs, we set out to combine a known receiver capability, very fast scanning techniques, a versatile display and a digital-processing capability which could utilize the information for handoff to other receivers and for transfers to a larger computer for subsequent processing. It is the object of this paper to describe the results of this research and development program and to describe some of the tradeoffs involving the processing and control portions of the equipment.

Signal Processing

A block diagram of the WJ-9195C Rapid Acquisition Spectrum Processor System is shown in Figure 1. The rf front end is similar to most superhetrodyne systems of this type. The rf input signal is routed through the antenna switch to the rf tuner/synthesizer and IF converter. These components are under control of the receiver control microprocessor. The tuner operates in a step mode when the system is scanning, and continuously when the system is used as a conventional receiver.

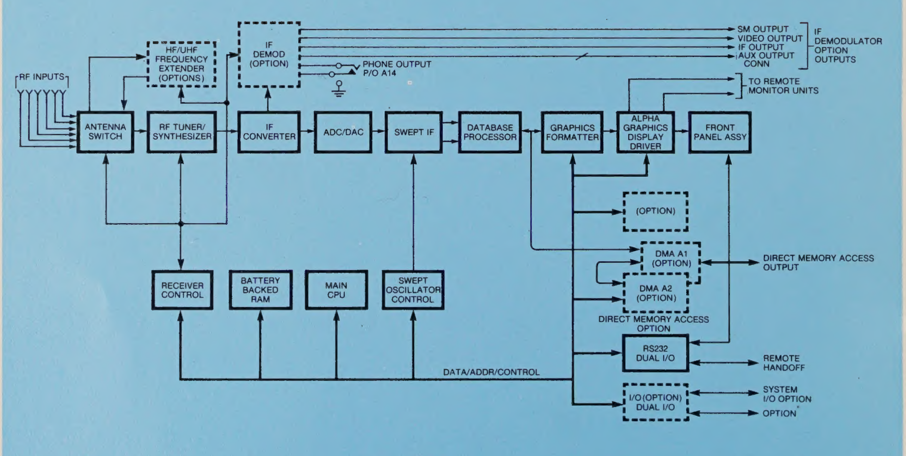

Figure 1. Simplified block diagram of the WJ-9195C.

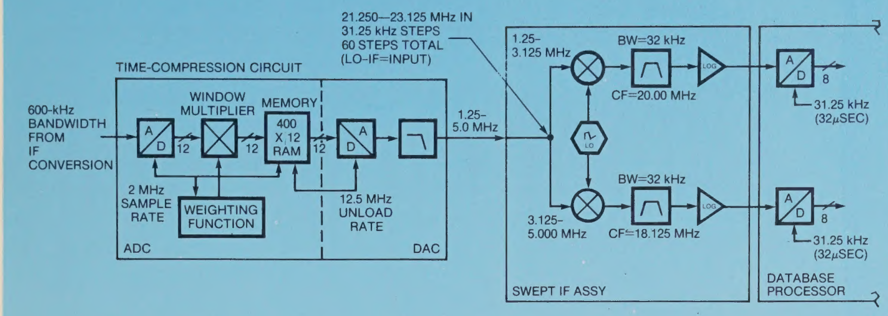

Figure 2. Simplified block diagram of a DSP subsystem (5 kHz resolution mode).

The receiver uses standard WJ-8628 receiver modules and operates from 20 MHz to 512 MHz. This can be optionally extended by the WJ-8628 HF Frequency Extender (FE) module down to 2 MHz and by the WJ-8628 UHF FE module to 1400 MHz. Higher frequency ranges are planned for the future. An IF demodulation option is also available so that the system can be used as a conventional receiver.

The output of the IF converter is fed to the ADC/DAC, swept IF (filter) and data-base processor. These modules form the digital signal processing (DSP) subsystem of the WJ-9195C. A simplified block diagram of this subsystem is shown in Figure 2. It consists of an ADC, a windowing operator consisting of a digital multiplier and stored weighting function, a DAC, a swept filter, and a second ADC and associated storage logic.

The receiver steps in discrete increments of either 600 kHz (to give a 5-kHz resolution) or 3 MHz (to give a 25-kHz resolution). After the receiver has achieved signal lock at a step, the ADC takes 400 samples. This is a sample rate of approximately 3.3 times the input bandwidth, so that the aliasing errors do not affect the desired dynamic range. When the digitizing has been completed, the receiver is tuned to the next frequency. This overlaps the receiver tuning time with the signal processing and results in a faster scan rate.

Signal processing theory shows that any pure signal which is collected over a finite time interval results in a Sin (X)/X spectrum, as shown in Figure 3. The spectrum may be viewed as the effective response of the filter to a sine wave. This type of filter response is not desirable because the large sidelobe levels will overlap nearby signals. It is necessary to suppress the sidelobes by use of a weighting window which multiplies each successive time sample by a weighting factor to compensate for the effects of the finite data block. The Hanning window function is used in the WJ-9195C, as shown in Figure 4. This results in a 32-db attenuation of the first sidelobe vs 14 dB for no weighting, 12-dB/octave rolloff vs 6 dB, all at the expense of only 1.8-dB loss in signal-to-noise ratio and a 65 percent widening of the central response.

The output of the window multiplier is stored for subsequent processing to transform this data into its spectrum. Several alternatives can be used to obtain the spectrum. These range from a purely digital approach to those which use a bank of tuned filters. The

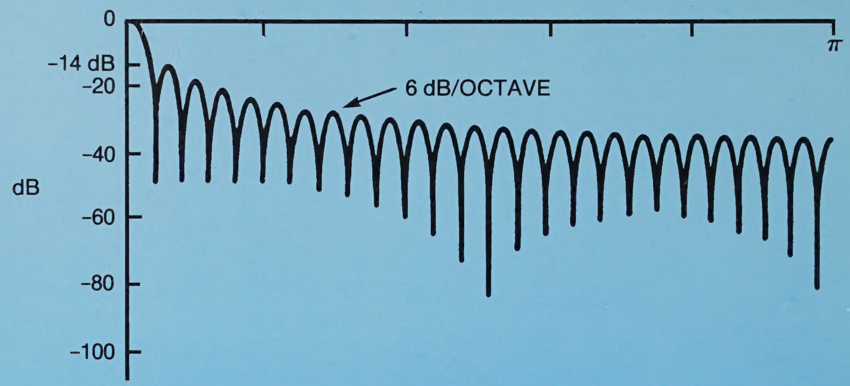

Figure 3. Spectral envelope of a finite time-interval sine wave.

WJ-9195C uses a time-compression method, using a combination of analog and digital hardware.

The basic time-compression technique has been previously described (1). In summary, it is almost the same as a standard sweeping spectrum analyzer except that time data is compressed, allowing the analysis to be preformed by wider filters. The speed-up or time compression is accomplished by taking the output data samples from the windowing multiplier and storing them in a memory, then reading them out at a higher rate. For a 5-kHz resolution, the 600-kHz band is sampled, windowed

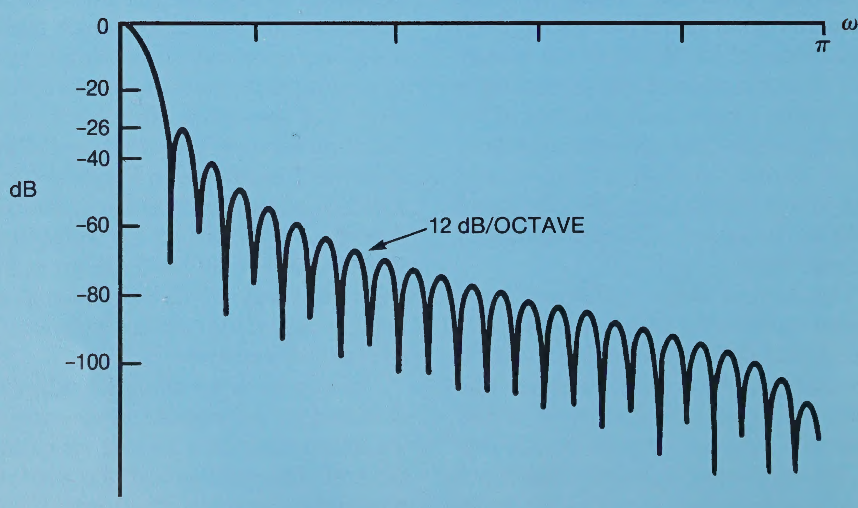

Figure 4. Spectral envelope of a Hanning windowed sine wave.

and stored at a 2-MHz rate, then unloaded at a 12.5-MHz rate. For a 25-kHz resolution, the 3-MHz band is sampled and stored at a 10-MHz rate. It is unloaded at the same 12.5-MHz rate.

The digital data unloaded from the RAM at a 10-MHz rate is converted to an analog signal having a bandwidth of 3.75 MHz centered at 3.7 MHz, using a 12-bit DAC.

This analog signal is split, upconverted and directed to a pair of offset 32-kHz bandwidth IF filter/detector/logamps.The up-converter uses a single voltage-controlled oscillator, which tunes the range 21.5 to 23.15 MHz in 60 steps of 31.25 kHz. Due to the speed-up accomplished in the time compression circuit, these 31.25 kHz oscillator steps correspond to 5 or 25-kHz steps at the original signal frequency, depending on the speed-up ratio employed. The use of two offset filter/detectors allows 120 samples of the 600 kHz (or 3 MHz, depending on the ADC sampling rate) IF passband to be acquired in 60 steps of 5 kHz (or 25 kHz) rather than 120 steps; thus, doubling the effective scanning speed of the system.

Each set of stored values in the RAM are read out 60 times; once for each of the 60 steps of the oscillator. Since the resolution bandwidth is determined by the final IF bandwidth and the ratio of ADC-to-DAC conversion rates, the same DAC output rate and filter steps can be used for both the 5-kHz and 25-kHz resolution modes. In both cases, this DAC readout rate is faster than the digitizing rate, so that a further increase in system scan rate is achieved. Each of the filter/DET outputs is digitized and stored in the data-base memory. Each successive sample is stored in the next successive memory location so that at the completion of each scan the memory will contain all the samples collected during the scan and the address of the memory cell will correspond to the frequency of the sample.

The memory containing the spectral data is contained on the data base processor unit. This memory can be accessed by the graphics formatter processor (GFP) and the optional direct memory access (DMA) board. The GFP is used to format the data for display on the front panel electroluminescent (EL) panel according to the parameters which have been selected by the operator. The GFP also processes the signals for automatic handoff to the other receivers connected to the system.

The DMA option provides transfer of the spectral data to a mainframe computer over an IEEE-488 bus. This bus provides a transfer rate in excess of the 40,000 spectral points per second required for a 25-kHz resolution at a sweep speed of 1 GHz/second. Control of the DMA transfers and of the wideband system by the mainframe computer is through an optional RS-232 or IEEE-488 port provided for this purpose.

System Control

A broadband rf spectral data acquisition system must acquire and display the data and must provide for operator control of the scan and other parameters. It must also perform functions related to the use of the acquired data. These include:

- setup and control of receivers and other devices associated with the wideband system.
- Transfer the data to a larger computer and provide for control of the system by that computer.

These functions pose problems in system design, since the operator input and response, the interface to receivers and other devices, and the interface to a larger computer require responses which are independent and unrelated to the scan timing and control. The

WJ-9195C must synchronize the control and processing of the scan data with the operator interface and with the setup and control of the receivers such that each does not conflict with the normal control sequences. For example, if an operator changes the beginning and/or end points of a scan during the scan, the changes to the scan logic must wait until the current scan is completed, or indeterminate operation will result.

Simple solutions where a function is performed only after the previous one has been completed cause a number of undesirable results, such as slow response to operator inputs and reduced scan rate. Satisfactory solutions require use of a single processor using a real-time mutlitasking operating system or multiple microprocessors. Synchronization of the individual microprocessors within the multimicroprocessor system usually requires that one or more of the microprocessors be capable of multitasking.

The WJ-9195C System using five microprocessors and a hardwired logic sequencer (i.e., state machine) is shown in the block diagram of Figure 1. The signal path is shown across the top. The state machine is contained on the high-speed ADC unit and is used for the control of the scan hardware. This provides much faster sequencing than would have been possible with a software-based microprocessor and results in a scan rate which is in excess of one gigahertz per second.

The five microprocessors are used as follows:

1. Main CPU (NSC800)—System control and handling of the operator input and response.
2. Front Panel CPU (NSC800)—Front Panel Keyboard and LCD Display Panel Control.
3. Receiver Control CPU (8031)—Control and stepping of the receiver.
4. Data Base Processor (8086)—Storage of the display data.
5. Graphics Formatter (TMS32020)—Formating and control of the display data.

The Main CPU uses a real-time multitasking operating system. One task handles the operator input and response, one task handles remote control from a mainframe computer, one task handles the monitoring and control of the handoff receivers connected to the system and one task handles the update of the parameters from the TMS32020. Interrupts are used to synchronize parameter transfers with the state machine.

The graphics formatter formats the data according to the paramters set up by the system operator. This requires calculation of the horizontal and vertical scale factors and other computations which are best handled by a processor with very fast arithmetic capabilities. The TI TMS32020 was chosen because it performs a 16 × 16 multiply with a 32-bit result.

The other microprocessors perform tasks previously implemented with discrete logic, but which are now more efficiently implemented with microprocessors.

The use of five microprocessors provides a great deal of flexibility in system design. Functionality can easily be added or modified. Effective use of this many microprocessors requires the interaction between them to be limited. Each microprocessor performs its task largely independent of any of the others. During power-up, each microprocessor performs a self test. Then, each receives the initial set of operating parameters from the Main CPU microprocessor (MCPU), in its turn. Finally, each starts execution in unison on the receipt of the End-of-Scan (EOS) synchronizing signal.

A similar procedure is followed when the scan parameters are changed by the operator or by a remote computer. First, the MCPU transfers the new scan parameters to each microprocessor during the current scan. Each microprocessor stores these new parameters in a temporary buffer. Then, at the end of that scan, each of the microprocessors gets the parameters from the temporary buffer and sets it up processing for the next scan, based on these new values. Here again, EOS is used as a synchronizing signal.

The use of a single microprocessor for setup has a number of advantages. First, the initial or default parameters are stored in one place. Secondly, the computation of all of the control of the system is also in one place. This is convenient when it is desired to change or add functions to the system.

The processing, format, transfer, and setup of the scan parameters becomes increasingly more difficult as more microprocessors are added. In addition, it is more difficult to partition the system work among the greater number of processors in a fashion that maintains the independence necessary to justify the use of an additional microprocessor. Therefore, there is an upper bound in the number of microprocessors that can be employed in any system.

The WJ-9195C uses interrupts followed by "handshakes" to assure that the microprocessors start up in the proper sequence. The main CPU checks the battery backed-up internal memory to determine if a full initialization is needed. If memory contains valid parameters, startup is made using the parameters that were previously input by the operator. In this case, the scan limit, lockouts, resolution, etc. are preserved. If any parameter is invalid, startup is made with the default values. The value parameter tests are intricate because it is not always easy to tell the difference between an internal memory with random data and one with valid parameters.

An end-of-scan (EOS) signal is generated by the receiver control CPU. This is used to synchronize all parameter changes, such as resolution, scan type and scan limits between the microprocessors. This CPU also generates a LOCK signal which synchronizes each step of the receiver with the state machine. The software is organized so that all of the scan control parameters are formatted when they are input by the operator and not when they are used at EOS. This allows the scan to run faster and provides for flexibility in programming the scan.

Since all scan parameters are reinitiated at the end of each scan, alternatives to the simple method of scanning from the minimum possible frequency (2 MHz) to the maximum possible frequency (1400 MHz) can be used, which increase the revisit rate and/or give priority to particular segments of interest. A partial scan can be made from the minimum displayed frequency to the maximum displayed frequency or only for the frequencies displayed on each trace. Lockouts can also be skipped. Alternately, certain bands can be revisited more often than other bands.

Handoff

An important use of the data acquired is to identify signals and to set handoff receivers to these signals. This can be done by an operator viewing the data on the display. Or, the process can be automated.

In the simplest method, a cursor is provided which can be moved along the frequency/amplitude display traces of data while the frequency corresponding to the cursor position is displayed. First, the operator sets up the handoff receiver for the desired frequency band, IF bandwidth and modulation type.

Then, the operator performs handoff by centering the cursor on a signal of interest, reads the cursor frequency and manually tunes the receiver to the desired frequency.

This process can be improved by adding the capability to the wideband system to remotely control the handoff receiver. In this case, the operator pushes a handoff button on the wideband system after setting up the handoff receiver and positioning the frequency cursor on the display instead of manually tuning the receiver.

The current WJ-9195C provides this cursor-driven handoff system. Under development is an automatic handoff system. In the automatic handoff system, the operator inputs the handoff parameters and the wideband system provides both the signal selection and the setup of the handoff receiver.

The handoff parameters consist of:

1. Frequency Band to Perform Selection
2. Selection Parameters
3. Disconnect Parameters
4. Handoff Receiver to Use
5. Receiver Setup
6. Priority
7. Time of Day

One or more frequency bands can be set up to search for signals to handoff to receivers connected to the system. The selection parameters consist of both signal-amplitude threshold and duration. The amplitude can be an absolute level or relative to the noise baseline (either average, peak or rms), and the selection can be made on any value which exceeds the threshold for the specified duration or only a signal which appears after the setup by the operator (i.e., a new signal). The ability to use new energy as a criteria for selection simplifies the operator setup because it is not necessary to exclude fixed signals such as local transmitters and TV stations from the handoff selection bands.

A simple criteria is currently being used to discriminate between the single and multiple-signal cases. The wideband system selects two signals for handoff when there are two signal peaks which are greater than the handoff threshold and the valley between them is 10-dB down from both peaks. The center of each lobe surrounding the peak is used as the handoff frequency.

Some errors are expected in determining whether one signal is present or two or more adjacent signals. This can be understood by considering the three cases illustrated in Figure 5a, 5b, and 5c. In the first case, a smaller signal is followed by a larger side. The third case is the mirror image of the first. Now refer to the signal shape shown in Figure 4, caused by the Sin(X)/X and windowing effects described previously. It is easy to see the similarity between 5a and 5c and the Sin(X)/X display.

Other problems in adjacent signal discrimination are caused by noise, signal jitter, and modulation. For example, double-sideband suppressed-carrier signals may appear as two independent signals, since the absence of the carrier may create a valley between the two sidebands (see Figure 5b).

On the other hand, adjacent signal problems do not represent a high percentage of handoff candidates, and errors which result in one signal being passed as two do not result in any loss of data, only the extraneous use of a handoff receiver.

Additional discrimination of signals can be achieved by allowing signal selection by priority and time of day and by providing the capability of assigning certain receivers to limited frequency bands.

The disconnect parameters establish the condition for which the handoff receiver will become available for use

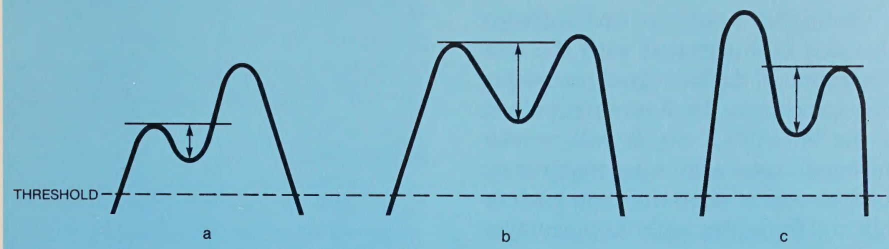

Figure 5. Adjacent signal discrimination.

with a new signal. In some cases, it is desirable to specify that the receiver is to remain tuned to a handoff frequency until it is reset by the operator.

Since the same receiver will be used for a succession of different signals when receivers can be automatically disconnected and connected, it may be necessary for the wideband system to output to a log printer a time history of the settings of each of the handoff receivers.

Mainframe Interface

Another important use of the spectral data from the wideband system is to transfer this information to a large computer for additional processing. A sweep rate of one gigahertz per second at a 25-kilohertz resolution translates into a date rate of 40,000 data points per second. This transfer rate can be accommodated by either IEEE-488 or a MIL-STD-1553 interface. The RS-232 interface is not fast enough for this purpose. The WJ-9195C provides an IEEE-488 interface for direct memory access (DMA) transfers from its data base directly to a mainframe computer.

It is desirable for the mainframe computer to provide control of the transfers and of the scan parameters when data transfers are provided from the wideband system to a mainframe computer. Since this remote control is independent of that set up by the operator, provision must be made to lockout one or the other. Some sharing of the setup can be made between the remote and local control.

The WJ-9195C Main CPU uses one task for the operator interface and one task for the remote control. The operator selects either remote or local control.

Summary

This paper has described the diverse technologies which must be integrated to form a complete wideband scanning system. The rf front end and the digital signal processing unit must provide fast scan rates over a broad band of hf, vhf, and uhf frequencies. It must also provide good sensitivity, selectivity, and wide dynamic range for a diverse range of signals. The digital hardware must provide control and data formatting in a flexible and efficient manner.

The WJ-9195C is an efficient and highly flexible system which uses a modular approach that incorporates the existing WJ-9040 receiver. The digital signal processing and formatting hardware runs under control of a table-driven multitasking operating system and provides ease of use by an operator.

It also provides the capability to adapt to future system requirements and host computer interfaces.

The digital hardware and software also can be integrated with the new generation of digital signal-processing microprocessors for future derivatives of the WJ-9195C, which will provide the much faster scan rates required for the intercept of short-duration push-to-talk and frequency-agile (hoppers) type signals.

Acknowledgements

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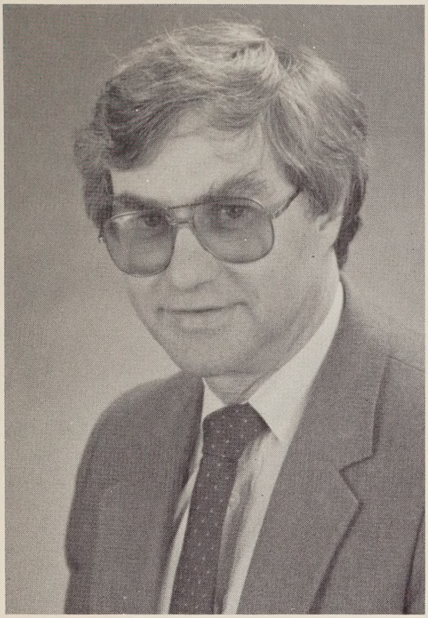

Allen L. Shapiro

Mr. Shapiro has extensive experience in computer architecture communications and software development, and has had experience with a broad range of microcomputers, minicomputers, and mainframes. He holds patents on a unique input-output system for minicomputers and on a method of employing a second-level read-only-memory in microprogramming, which is used in the NCR, SEL, and other minicomputer systems.

While at Watkins-Johnson Company, Mr. Shapiro was responsible for the software architecture and implementation of the WJ-9195C Rapid Acquisition Spectrum Processor.

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