WATKINS-JOHNSON COMPANY
3333 HILLVIEW AVENUE
PALO ALTO, CA 94304
(415) 493-4141

BULK RATE
U.S. POSTAGE
PAID
PERMIT NUMBER
173
MILPITAS
CALIFORNIA

WATKINS-JOHNSON

Facility Locations

United States

CALIFORNIA

Watkins-Johnson
3333 Hillview Avenue
Palo Alto, 94304
Telephone: (415) 493-4141

Watkins-Johnson
2525 North First Street
San Jose, 95131
Telephone: (408) 262-1411

Watkins-Johnson
440 Kings Village Road
Scotts Valley, 95066
Telephone: (408) 438-2100

MARYLAND

Watkins-Johnson
700 Quince Orchard Road
Gaithersburg, 20878
Telephone: (301) 948-7550

International

UNITED KINGDOM

Watkins-Johnson
Dedworth Road
Oakley Green
Windsor, Berkshire SL4 4LH
Telephone: (07535) 69241
Telex: 847578
Cable: WJUKW-WINDSOR

ITALY

Watkins-Johnson S.p.A.
Piazza G. Marconi 25
00144 Roma-EUR
Telephone: 59 45 54
Telex: 612278
Cable: WJ ROM I

GERMANY, FEDERAL REPUBLIC OF

Watkins-Johnson
Keferloher Strasse 90
8000 Muenchen 40
Telephone: (089) 35 97 038
Telex: 509401
Cable: WJDBM-MUENCHEN

Watkins-Johnson
Deutschherrenstrasse 46
5300 Bonn 2
Telephone: (228) 33 20 91
Telex: (886) 9522
Cable: WJBN-BONN

The Watkins-Johnson *Tech-notes* is a bi-monthly periodical circulated to educational institutions, engineers, managers of companies or government agencies, and technicians. Individuals may receive issues of *Tech-notes* by sending their subscription request on company letterhead, stating position and nature of business to the Editor, *Tech-notes,* Palo Alto, California. Permission to reprint articles may also be obtained by writing the Editor.

Printed in U.S.A.

VOL. 11 NO. 6 NOVEMBER/DECEMBER 1984

Software Design of Microprocessor-Controlled Receivers Part I

WATKINS-JOHNSON COMPANY

Tech-notes

Many new receiver designs include microprocessor control circuitry which replaces the more rigid hardware circuits previously used. Its software architecture lends itself to designs that permit the microprocessor to control functions previously requiring complex hardware configurations. The results of software control provide performance and specifications that equal or exceed hardware designs, while providing reductions in cost, size and power consumption. This two-part article discusses the advantages of software control.

Introduction

Servo loop theory, as implemented in software/hardware design, is utilized to create more flexible receiver functions. Receiver Automatic Gain Control (AGC), when implemented by software, provides superior performance with more diversified attack and decay times to meet the specific requirements of the different types of detection modes. Automatic Frequency Control (AFC) operates as an ideal function, not limited by hardware design constraints. The Beat Frequency Oscillator function (BFO), when implemented in software, substantially reduces hardware requirements. Using special software routines, fast frequency scanning can be performed with synthesizer-like accuracy. Special routines also substantially reduce receiver downtime by providing built-in test and internal diagnostics functions which locate and define receiver faults.

Software AGC

Automatic gain control permits a receiver to change its gain characteristics, keeping a constant signal amplitude at the AM detector. When the types of modulation as well as control range are as diverse as in a surveillance receiver, the AGC requirements become extremely complex. The rate of AM modulation, SSB attack and decay time, pulse and CW reception (all over a signal amplitude range in the order of 100 dB) demand a rigidly designed AGC circuit. Fortunately, the software design can use tools beyond normal components such as sample-and-hold-forever and sample-and-forget routines. Figure 1 illustrates a simplified block diagram of a typical receiver/microprocessor interface.

The simple block diagram of the microprocessor section is similarly repeated for each software function. However, space is conserved by using 16 input A/D converters and other multifunction integrated circuits.

Overview of Software AGC

In a software AGC system, the microprocessor is placed at the control point of the loop. It obtains signal level information from the AM, AM peak, and LOG detectors, and has gain control at various points in the signal path. The signal level is sampled, and the gain is adjusted for optimum performance. Depending on the type of signal being detected, the AGC characteristics should be changed to provide the ideal results. With hardware AGC, this requires different AGC control circuits, which would be space prohibitive in a compact receiver. Software AGC, however, allows various attack, decay and hold characteristics without, additional hardware cost or space requirements.

A flow chart showing the operation of a software AGC system is shown in Figures 3, 4, and 5. This system offers two types of AGC characteristics. The first is a fast attack, fast decay which is intended for AM or FM operation. The other is a fast attack, hold and slow decay, for use with PLS, CW and SSB operation. The goals and operational

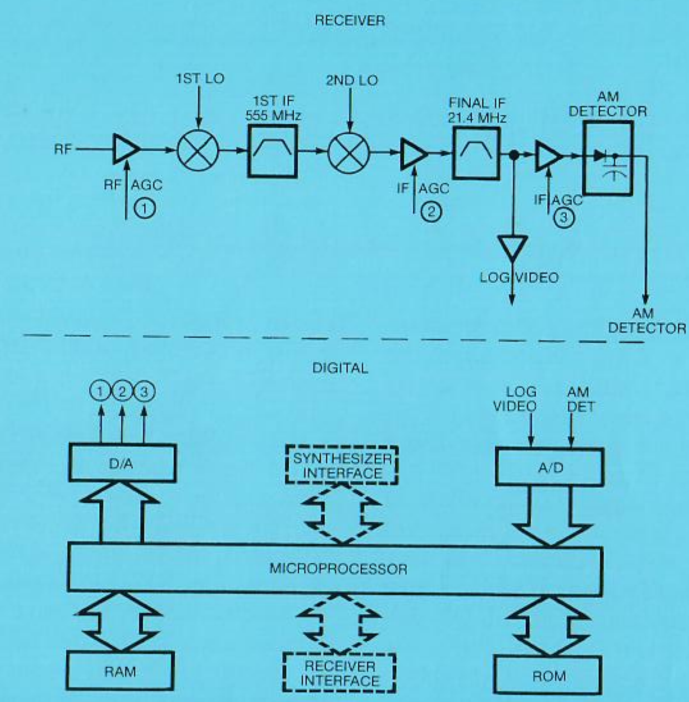


Figure 1. Software-controlled AGC.

characteristics of both types of AGC will be explained in the following paragraphs.

The fast attack, fast decay AGC is intended for signals with constant carriers. While in this AGC mode, the AM detector is sampled using a pattern that is non-repetitive for time periods less than 25 ms. This non-repetitive sampling is important, as it avoids the chance of the software being synchronous with the modulation of the carrier. It is required because the microprocessor does not sample the AM detector continuously, as in a hardware AGC configuration. Figure 2 illustrates an example of the non-repetitive sampling.

The A/D converter input from the AM detector is averaged in a low-pass filter, having a 3 ms time constant. By controlling automatic gain to the peak value read on the AM detector during each 25 ms sample window, the AGC action will function properly on low duration, low repetition-rate modulation schemes. By peak picking the AGC, it is capable of working reliably without tracking modulation on signals having repetitive rates as low as 40 Hz. This allows the decay time to remain very fast (75 ms for a 50 dB change).

After the peak value of the sample window is picked, the microprocessor will adjust the gain controls to center the signal at the optimum point within the AM detector range. The software allows for two correction rates. If the signal is greater than 10 dB from the optimum point, the AGC goes to a fast mode, where 10-dB corrections are made every 5 ms until the signal is

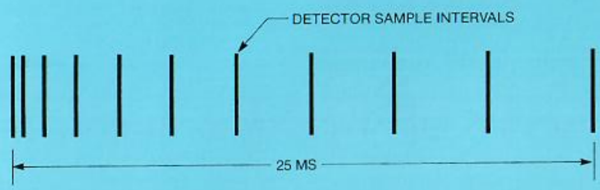


Figure 2. Non-repetitive AM detector sampling.

within ±10 dB of the optimum point. Once that level has been obtained, the software AGC switches to slow correction. In this mode of operation, 1 to 3 dB corrections are made at a rate of one every 25 ms. Once the gain control has been adjusted to place the signal within 3 dB of the optimum point on the AM detector curve, no further corrections are made until the signal deviates from this 3-dB dead zone. The AGC will stay in slow correction unless the signal exceeds the ±10-dB limit, at which time fast correction is re-entered.

The fast attack, hold, slow decay AGC, which will be called HOLD AGC, is used for receiving signals with pulsed carriers. The attack characteristics of this type of AGC are the same as those explained for use with AM or FM detection. Instead of the typical slow-decay AGC for this type of signal reception, a hold, slow decay is created in software. This means the signal does not have to be re-attacked, as the software AGC is capable of holding the exact level that was present before the signal went off the air. If no signal reappears within a predetermined time, a slow decay will be started. This type of intelligent AGC, which would be difficult to implement in hardware, is a simple task for software.

Discussion of AGC Flow Charts

The following paragraphs explain the software AGC flow charts illustrated in Figures 3, 4, and 5. The AGC control is shown in Figure 1. Figure 3 shows the initilization of the LOG COUNTER to control the timing for the non-repetitive sampling. It is loaded to 10. The AM VAL, a storage location for the peak AM detector reading, is located to 0. The software now decides which detector to read: the AM detector, if NORMAL AGC or the AM PEAK detector, if in HOLD AGC mode. Once the reading has been taken, a decision to enter into NORMAL OR FAST AGC is made. If FAST AGC is entered, the current detector reading is stored in AM VAL. In NORMAL AGC, the larger of the new reading or the old reading is saved in AM VAL. For each count in the LOG COUNTER, the LOG detector is read and the COR LEVEL is tested (CHECK COR). After the last LOG reading, the LOG COUNTER is decremented and the loop, starting at the AM reading, is repeated until the LOG COUNTER is 0. At completion of the sample loop, control is passed to FINE AGC CORRECTIONS. This sequence tests for a signal 10 dB above the midpoint of the AM detector. If present, fast AGC is enabled and control is returned to AGC control. If no signal is present, the HOLD COUNTER is tested for 0, indicating the system has not detected a signal dropping below the lower 10-dB threshold. A positive response allows the lower 10-dB limit to be tested; if the signal is below this limit, and HOLD AGC is not on, FAST AGC is enabled and control is returned to AGC

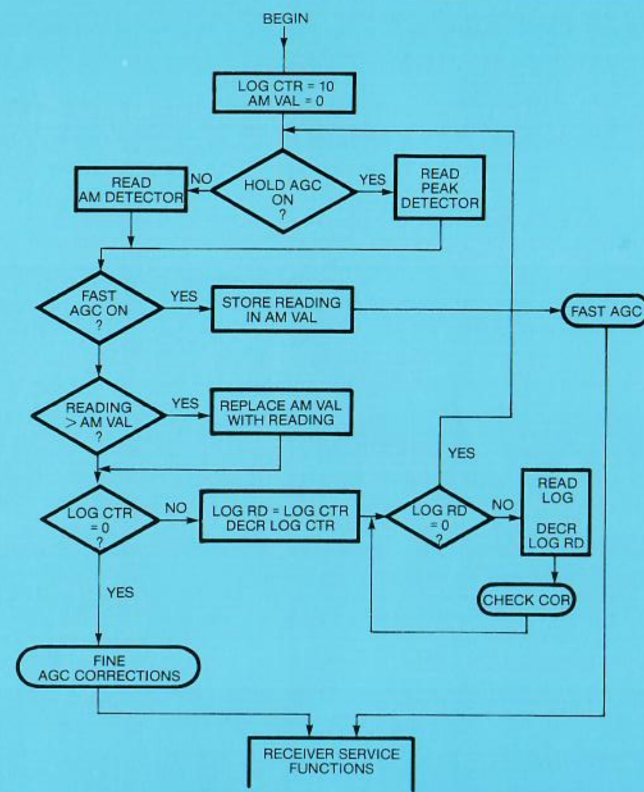


Figure 3. Flow chart software AGC control sequence.

CONTROL. In the case where HOLD AGC is enabled, the HOLD COUNTER is loaded to 60, which will cause no further decay for approximately 1.5 seconds. A negative response to HOLD COUNTER 0 test, indicates a hold in progress and bypasses the lower 10-dB limit test.

At this point, the dead-zone windows will be checked. If the signal is below the dead zone, and HOLD AGC is off, a correction to a maximum of 3 dB will be performed and control will be returned to AGC CONTROL. If HOLD AGC is on, the HOLD COUNTER is tested for one. If the test is positive, 1 dB of attentuation is removed and the HOLD COUNTER is loaded to four, causing a decay rate of 10 dB/sec. Control is then returned to AGC CONTROL. If the HOLD COUNTER was not one, the HOLD COUNTER is decremented and control is returned to AGC CONTROL.

When the signal is above the lower dead-zone limit, a test for the upper dead-zone limit is made. If the signal falls below this limit, AGC is at rest, no correction is required and control is passed to AGC CONTROL. A signal above the upper dead-zone limit causes a maximum of a 3-dB correction to be made. After this correction, control is given to AGC CONTROL if HOLD AGC is not enabled. In the case where HOLD AGC is enabled, the peak detector is dumped and HOLD

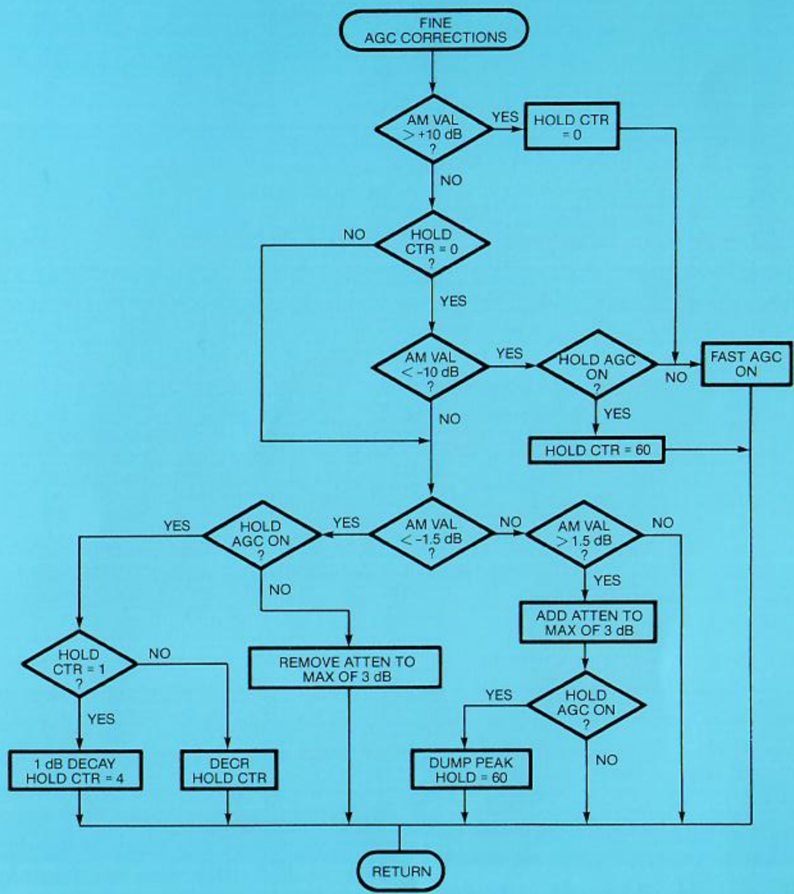


Figure 4. Flow chart AGC fine corrections control.

COUNTER set to 60. The peak detector is dumped so the results of adding attenuation can be sensed. The HOLD COUNTER is set so that the AGC will not start decaying as a result of the peak detector being dumped. Control is now returned to AGC CONTROL. This completes the discussion of the FINE AGC CORRECTIONS Flow Chart.

The remaining AGC flow chart is the section called FAST AGC (Figure 5). This section shows how fast corrections are made (approximately 10 dB/5 ms). The first test checks for a signal greater than 10 dB above the AGC point. If the signal is below this limit and above the lower 10-dB limit, FAST AGC is cancelled and control returned to AGC CONTROL. When the signal is above the upper 10-dB limit, 10 dB of attenuation is added. If HOLD AGC is on, the peak detector is dumped and HOLD COUNTER is set to 60. The AM PEAK detector is then read and control is given to AGC CONTROL. If HOLD AGC is off, control is returned to AGC CONTROL. In the case where the sig-

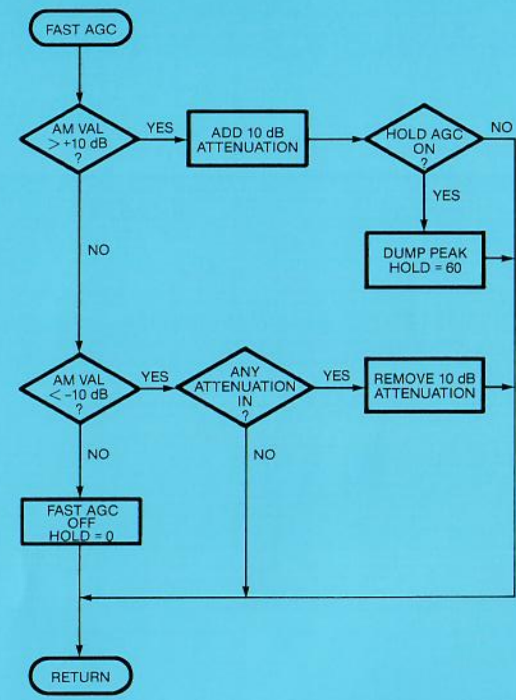


Figure 5. Flow chart fast AGC corrections control.

nal is below the lower 10-dB limit, 10 dB of attenuation is removed. The AM detector is read and control is returned to AGC CONTROL. This concludes the explanation of the AGC CONTROL Flow Charts.

Typical Software AGC Responses

Shown in Figures 6 through 9 are typical responses of the AGC loop to different types of signals. In each figure the top plot shows the signal applied to the input. The bottom plot shows the software AGC response, a typical hardware AGC response, and the AM detector window. The plots are shown as change in attenuation versus time. Figure 6 is the AGC response to a 22 dB increase in signal level while in the NORMAL AGC mode. The software AGC shows a fast response (10 dB/5 ms) until the AGC is within 10 dB of the signal. Then, slow corrections are made until the final value is reached. The plot shows the ability of the software to cause the AGC to slew very quickly to

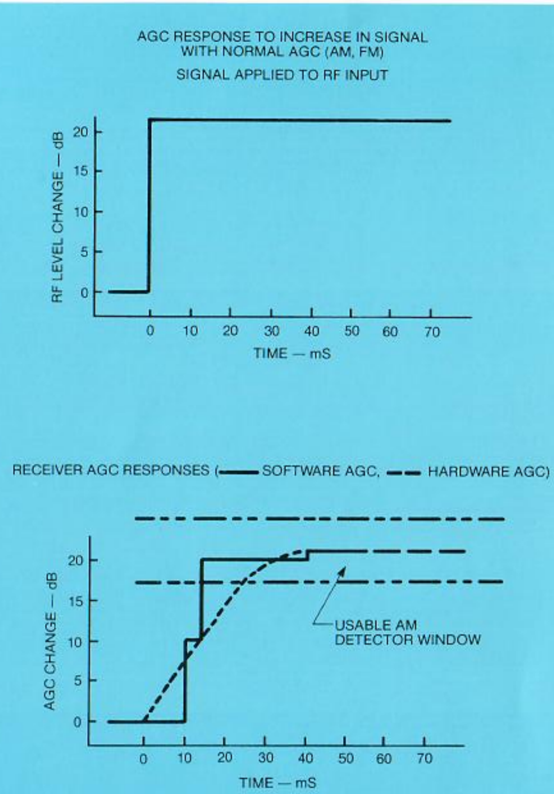


Figure 6. AGC response to increase signal.

within a few dB of the final value, and then change to a slower rate to make the remaining corrections. This increases the stability of the loop and helps avoid overshooting the final value.

Figure 7 shows the response of a 22 dB decrease in signal level while in NORMAL AGC. The software AGC enters the fast correction mode after sensing the signal below the 10-dB lower limit on the AM detector. In this mode it corrects at a 10 dB/5 ms rate until the signal is within the 10-dB lower limit. Then, in slow correction, it continues until the signal falls within the 3-dB dead zone of the AM detector. Since the software AGC must see the signal below the lower 10-dB limit for the full sample window, the decay is allowed to work quickly, without danger of the AGC following the modulation, as in a fast decay hardware AGC. The plot shows the software AGC settled within 60 ms, while the hardware AGC takes longer than 150 ms.

Figure 8 shows the AGC response to a signal that slowly decreases, drops out, then reappears at the original level. This example is shown using HOLD AGC, as used in PLS, CW, or SSB detection modes. In the case of the slow decrease, both types of AGC are able to follow the signal. When the signal drops out, the software AGC starts its

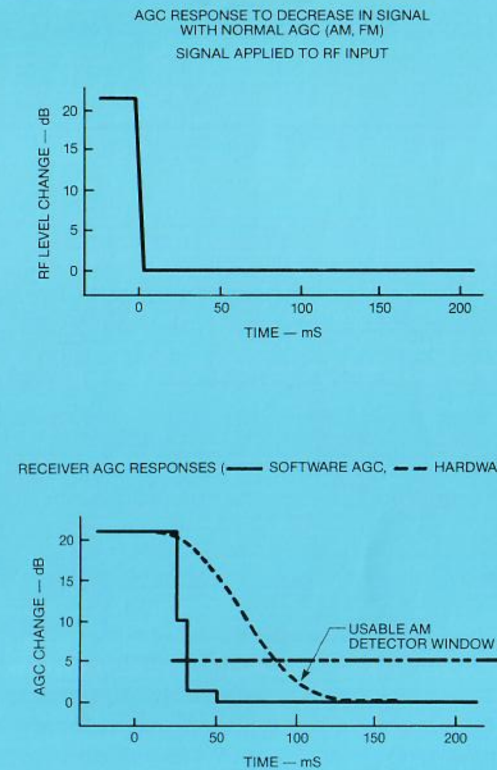


Figure 7. AGC response to decrease signal.

hold timer, keeping attenuation set at the last valid level, while the hardware continues to decay. When the signal returns, the software AGC still has the gains set to allow acquisition in the AM detector. The hardware must reattack the signal when it returns. After the signal drops out again, the hold is again restarted in the software AGC. Using its hold-forever ability, the software holds for approximately 1 second then starts a slow decay until it senses the signal return. The key here is the intelligent ability of the software AGC to follow a small signal change and hold on a signal dropout.

Figure 9 shows the NORMAL AGC response to an 85-dB increase in signal level. One of the most significant abilities of software AGC is shown during a large signal change where the time savings of the dual rate is very important.

The other key advantage is that software AGC is a controlled loop, no matter where the signal is with respect to the current AGC level. In a hardware AGC circuit, once the signal is outside of the AM detector range, the system enters an open-loop condition. This could lead to a ringing condition as the AGC voltage tries to settle. The software AGC gives the receiver designer new tools that are only limited by his ability to provide the proper information to the programmer.

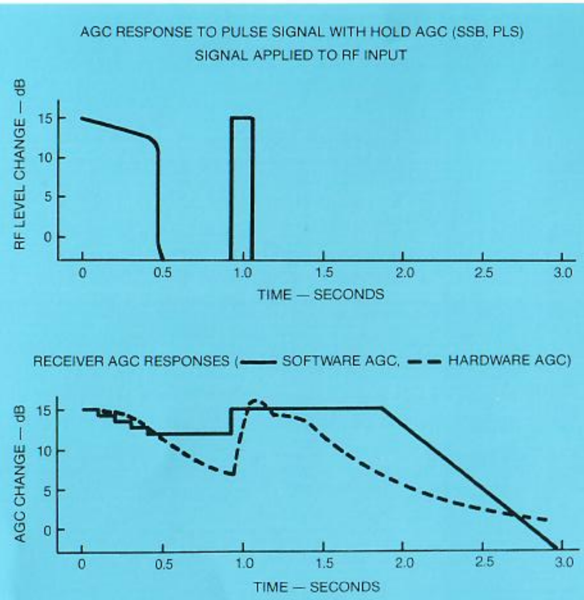


Figure 8. AGC response to pulse signals.

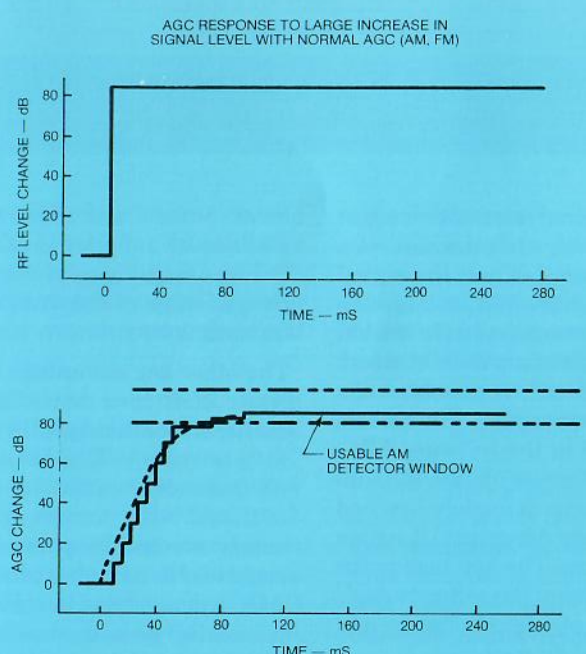
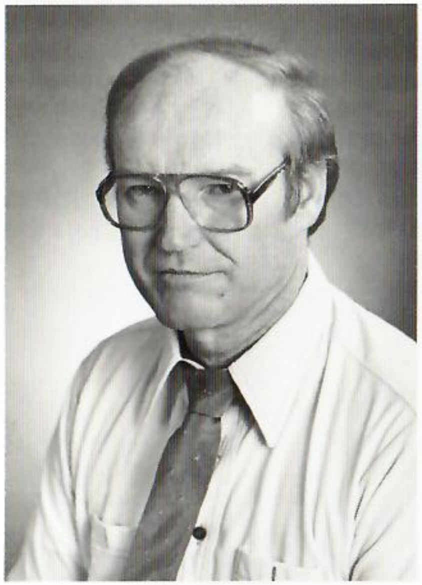
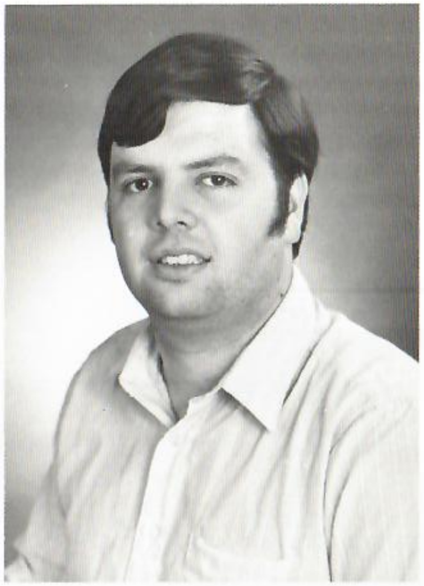


Figure 9. AGC response to a large increase in signal.

Authors:





Charles E. Dexter

Mr. Dexter is currently Manager, Surveillance Receivers, Special Projects Division. This includes the WJ-861X family of microprocessor-controlled UHF/VHF receivers, controllers and tracking preselectors.

He was previously Program Manager for the WJ-8718 HF Receiver, a high-volume version of the WJ-8888 HF Receiver. Before assuming responsibility for the WJ-8718 HF Receiver, Mr. Dexter was a member of the Advanced Development Section where new product ideas are evaluated. His responsibilities included advanced frequency synthesizer techniques to improve spectral purity and to make synthesizers more cost effective.

Mr. Dexter is a prolific writer and has published many articles on receiver concepts and designs. He holds a B.S.E.T. degree in Applied Science from Capital Institute of Technology.

Anthony W. Poffenberger

Mr. Poffenberger is Head, Digital Control Section, Surveillance Receiver Engineering, Special Projects Division. He is currently responsible for the design and development of all digital and microprocessor-related modules in surveillance receiver engineering. Recently, he designed the microprocessor section of the WJ-8615 compact receiver. He is presently designing the WJ-8610 system controller which provides operator control of 14 receivers.

Mr. Poffenberger holds a B.S.E.T. degree from Capital Institute of Technology.