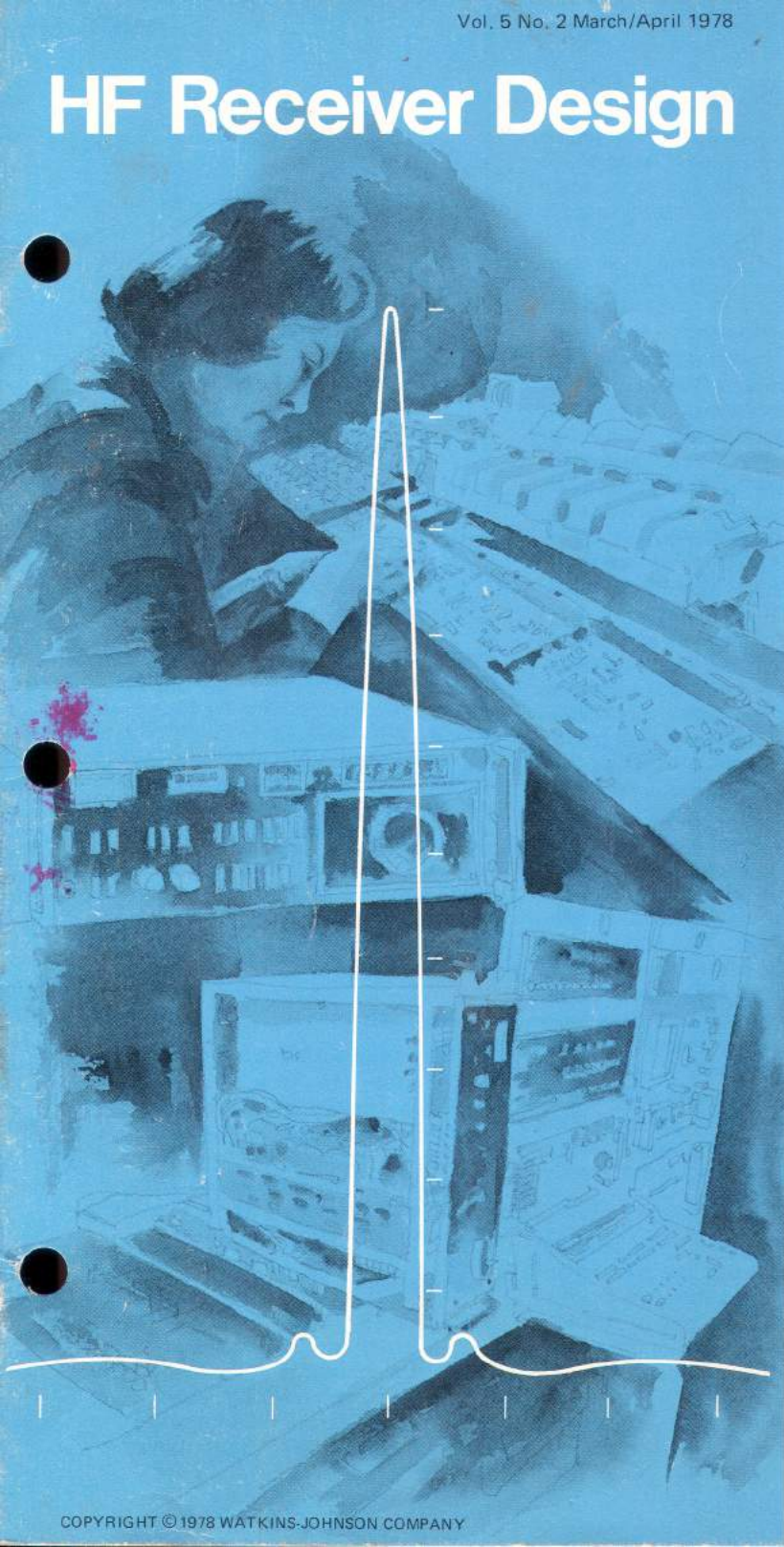


HF Receiver Design

WATKINS-JOHNSON COMPANY

Tech-notes



HF Receiver Design

The most widely-used frequency spectrum is the high frequency band of 0.5 to 30 MHz. Many HF Receivers, some of which have served continuously for the past twenty-five years, are used by government and amateur operators alike, and number in the hundreds of thousands.

In an age where technology is moving toward ever-increasing automation, the need for manually-controlled receivers has diminished, while the need for remotely-controlled receivers that require fewer operators has triggered a revolutionary change in receiver design concepts. Some of the improvements that have been made by manufacturers to their line of HF Receivers include ultra-high tuning accuracy, high dynamic range signal handling, and computer control of receivers. Although many receivers are designed to serve specific purposes, there is also a need for a low-cost, high-performance, general-purpose receiver that will meet the requirements specified by today's user. This article deals with the techniques, problems, and solutions encountered by the Watkins-Johnson CEI Division in the development of a low-cost, general-purpose receiver (WJ-8718). This article does not dwell on the theoretical electronic aspects which naturally embrace the development of any complex new product, but it does discuss the physical and mechanical layout techniques which need to be followed to produce a low-cost product that adheres to the strict specifications that are offered by more costly, special-purpose receivers.

The major concerns in the development of a general-purpose receiver are those of designing a low-cost product (about one-fourth the cost of standard receivers) and, at the same time, building into that product the high performance operation of the more costly receivers. To accomplish this task, it is necessary to develop special

techniques for fabrication, assembly, test, and component purchasing.

Fabrication

To keep manufacturing costs to a minimum, the fabrication of the Watkins-Johnson Company general-purpose receiver included elimination of all milling and tapping of chassis material; only punching, bending and casting of parts was allowed. Additionally, the requirement for loose hardware, such as nuts and washers, was kept to a minimum. Special emphasis was placed on the time required to wire the main chassis. Other electrical assembly requirements, such as pre-bending of components and machine-assisted printed circuit board assembly, were integrated into the fabrication design.

Because of the complex nature of the receiver, automatic test equipment was developed for module, receiver diagnostic, and final tests. Simplicity of receiver testing procedures provides an efficient method by which units can be tested by individuals possessing only basic technical knowledge.

As with most manufacturing projects that require a strict adherence to low production costs, purchase of parts is made on a high-volume basis, directly from the factory.

Performance

Some of the performance goals established for the new HF Receiver included stringent shock, vibration and temperature specifications, the capability of changing performance and control by addition or deletion of modules, and ease of troubleshooting and maintenance.

Engineering

Designing a general-purpose receiver within strict cost and labor boundaries led to the idea of dividing the receiver into plug-in modules by function, as well as designing these modules in such a way that for any necessary

repair or assembly, the number of solder connections is eliminated or, at least, minimized. Also, since the prevention of EMI (electromagnetic interference) and system overheating are problems that dominate receiver layout, new interconnection design ideas for solutions to these problems were developed. One additional provision to facilitate receiver fault analysis is the positioning of test points on a single side of the receiver. This will allow all fault locations to be made at the module level.

Receiver Layout

The proper receiver layout is the key to the solution of EMI and heat problems. A block diagram showing the interconnecting points of the HF Receiver is shown in Figure 1. The EMI and heat distribution, as shown in Figure 2, make it imperative that EMI-susceptible modules be separated from those generating EMI. It is also important that input/output and control lines not enter any compartments unless the compartments are EMI-neutral. Modules with inputs and/or outputs leading to any external parts of the receiver should be mounted against the rear panel, while neutral

modules can share the same area. Heat-generating modules should have access to a rear or side panel. Heat from the regulators will dissipate outside of the receiver. Once the proper module separations have been made, a re-interpretation of the original block diagram in physical form can be drawn, as shown in Figure 3.

The RF-input converter module, which is EMI-susceptible, is contained within a brass enclosure located as far away as possible from the synthesizer, since the synthesizer is an EMI generator. The high dynamic range of the RF converter requires large amounts of power to be dissipated internally. The converter is, therefore, mounted to the sideplate. Because the IF section is, in effect, a narrowband amplifier, it is less susceptible to EMI, although it does require a certain amount of shielding. The internal control section is implemented in low-power CMOS, and will not generate EMI. Control lines from the front panel or from external control need not be shielded if the other modules are sufficiently shielded. This arrangement provides efficient EMI control of the receiver and allows a through channel from the

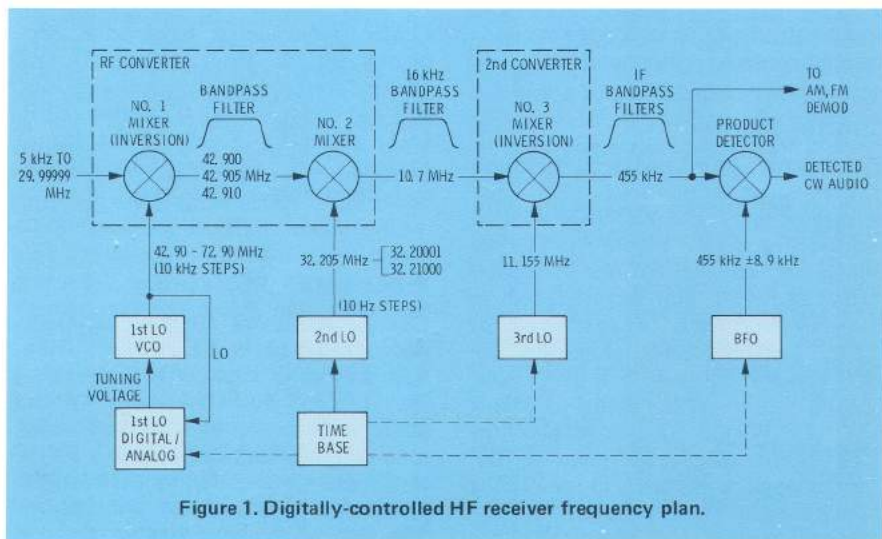


Figure 1. Digitally-controlled HF receiver frequency plan.

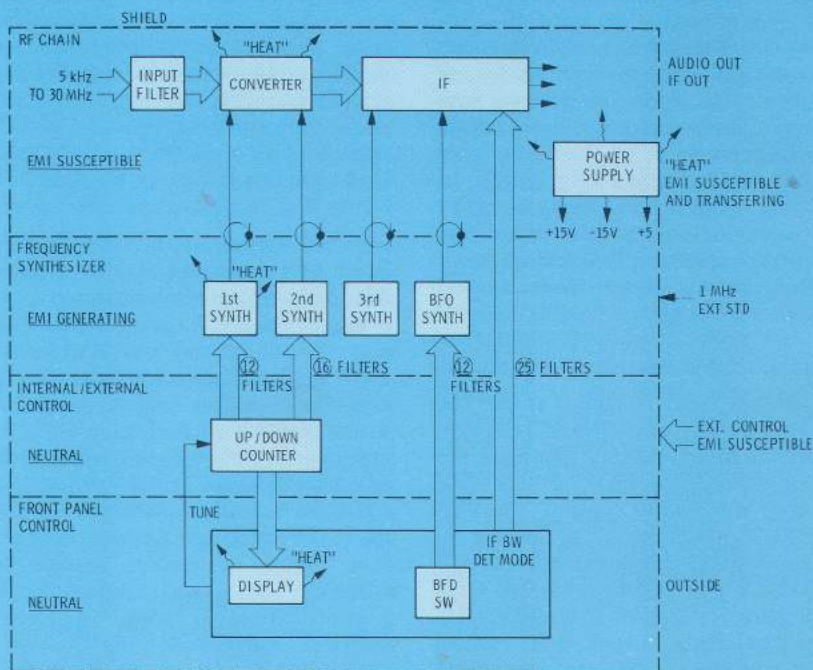


Figure 2. EMI and heat distribution of the HF receiver.

rear to the front panel for the remote/manual control requirements.

Control Section

The control section of the HF Receiver utilizes three connectors of a nine-connector input/output (I/O) control mother board (see Figure 4). The six remaining connectors are supplied $\pm 15V$ and $+5V$ and are designed to have an additional capability of 20 watts. Optional cards plug into the I/O control mother board. Present options and most future options will use plug-in ribbon cables for card interconnections. Some of the present options include: (1) Preselector Control (automatic selection of pre-selector bands), (2) Manual/Remote

Control (frequency bandwidth controlled by 32 lines), (3) IEEE 488 Digital Interface (total remote control), and (4) Independent Sideband (USB, LSB, or both). Some of the future options will include 1-Hz tuning and microprocessor control.

Problems and Solutions

One of the most complex problems encountered in the HF Receiver design was finding a method of controlling the receiver from the front or rear panel without the control lines acting as a coupling link between the RF/IF stages and synthesizer, or between the synthesizer and any external outputs. The cost of shielding a total of about

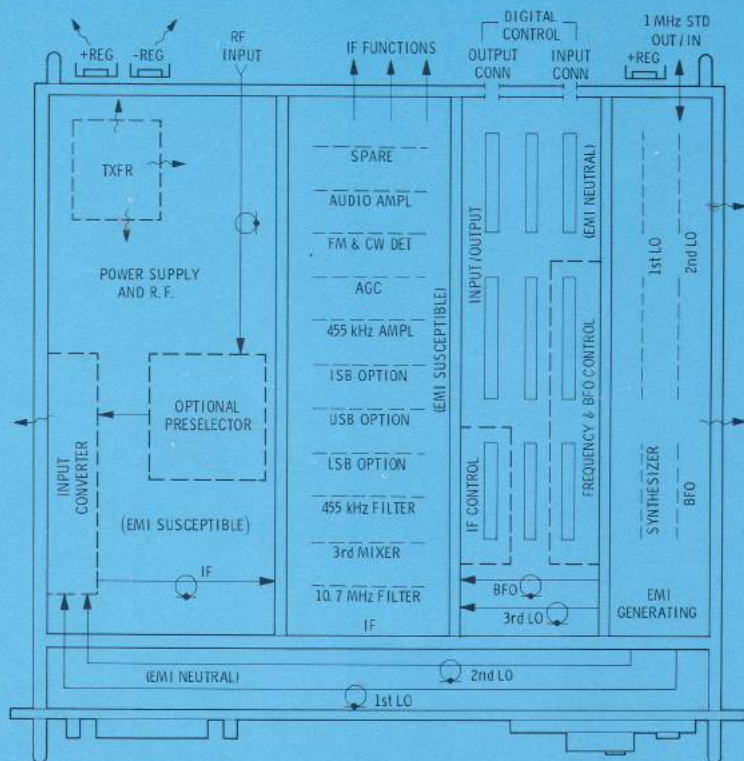


Figure 3. Digitally-controlled HF receiver chassis layout.

75 control lines between the IF and synthesizer control, utilizing low-pass filters with stop bands to the required gigahertz range, might easily exceed the cost of the entire main frame.

In search of a solution to the problem of control-line shielding, it was found that the use of single or tandem ceramic capacitors would provide unwanted signal attenuation only over a narrow frequency range, because of the resonant nature of the capacitor and its leads (see Figure 5). Also, lines connecting through a partition are affected by EMI signals due to the existence of exposed wire following the capacitor bypass. The combined solution to both problems is in the utilization of a special type of flat,

flexible cable to make interconnections. Each flat cable is wrapped with metal foil, which adds about 100 pF to each line, thus providing higher frequency filtering as well as a leadless ground. Two 29-line cables are used for the synthesizer section and one cable is used for the IF section of the HF Receiver (see Figure 6). The filtering provided by using the flat-cable technique is about one-fifth the cost of conventional line-filtering techniques.

Input Converter

The performance of a receiver is directly related to the design of the input converter. Generally, the material cost and direct labor necessary to pro-

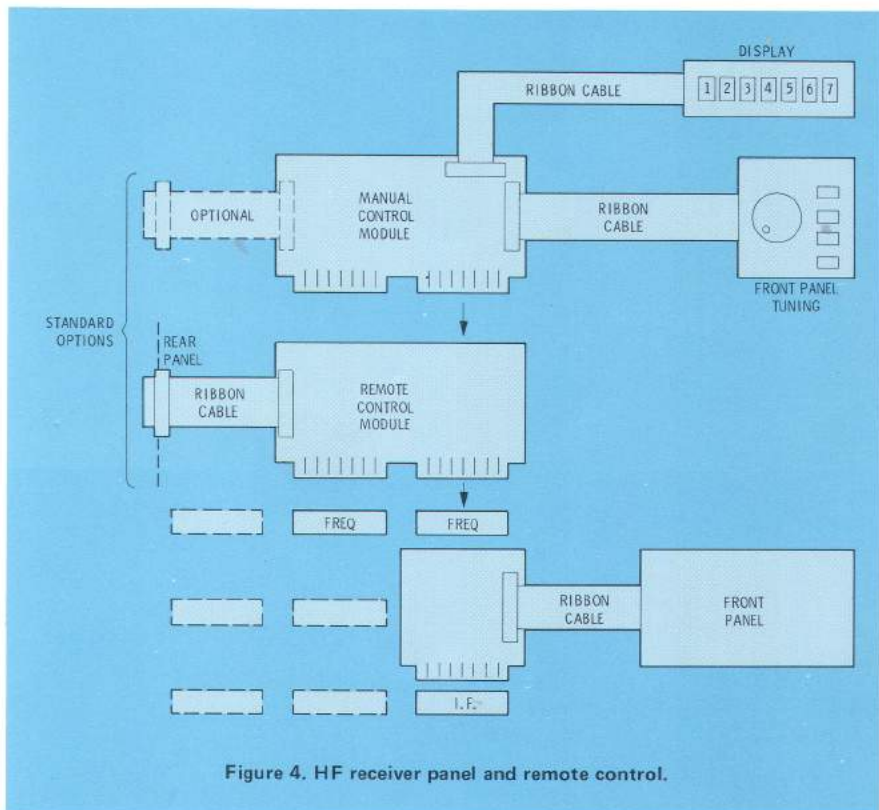


Figure 4. HF receiver panel and remote control.

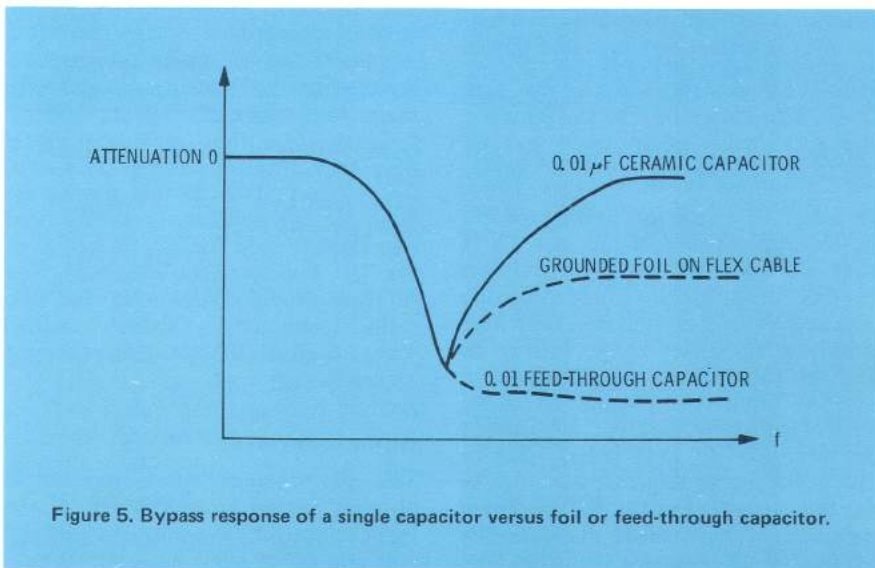
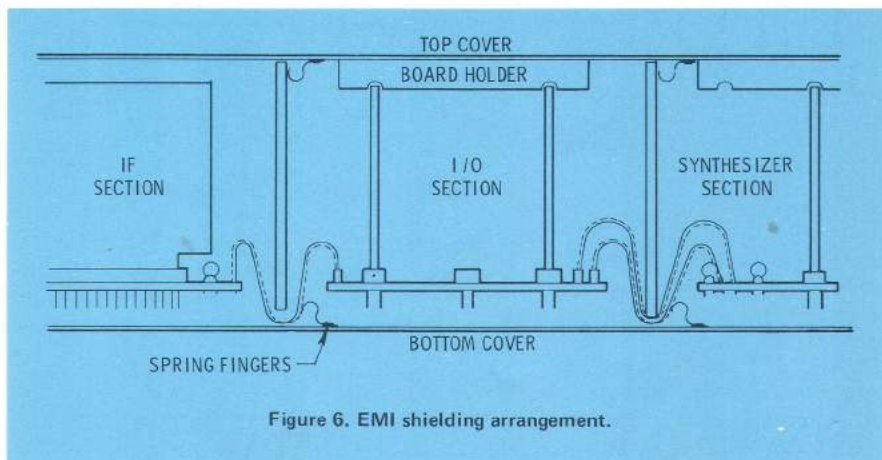


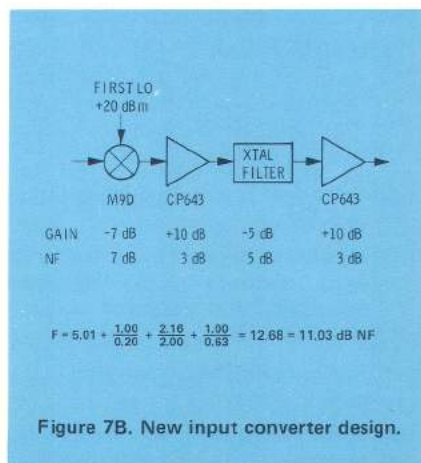
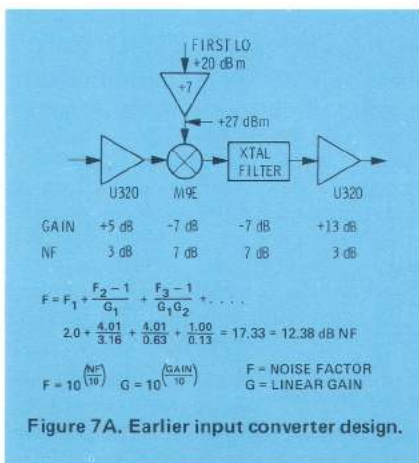
Figure 5. Bypass response of a single capacitor versus foil or feed-through capacitor.



duce the input converter module is such that it becomes one of the most expensive component parts of the HF Receiver. For example, the input converter may consist of a multi-partitioned brass box with point-to-point wiring and a dozen separate adjustments. A new design concept has reduced the HF receiver's input converter module to two printed circuit boards with one partition and two single, peak-tune adjustments.

A design comparison between an earlier converter and the new input converter is shown in Figures 7A and

7B. The previous design achieved greater than +20-dBm, 3rd order intercept point and less than 15-dB noise figure. The 8-dB amplifier located before the mixer is used to compensate for the loss of the mixer. To achieve the necessary specifications, the amplified signal requires a greater than 28-dBm, 3rd order intercept-point mixer and a 7-dB power amplifier to drive the mixer. Also, converter post stages need extra high signal-handling capability to maintain the required intercept point. From this simplified explanation of the operation of an earlier type of input converter, it can



be seen that to achieve the required noise figure, while maintaining the necessary signal-handling capability, an amplifier must be placed before the mixer; this arrangement causes an increase in the cost of the input converter stages.

In designing a general-purpose HF receiver, a large reduction in cost can be made by the elimination of the amplifier and by the reviewing of each stage for noise figure, 3rd-order intercept point, and gain. In the CEI design concept, these parameters were improved until the arrangement shown in Figure 7B was achieved.

All other assembly, such as main chassis wiring, is done using military-type crimping techniques. Much of the wiring is done by utilizing mother boards equipped with pressed-in, wire-wrap, printed-circuit connector pins. This type of wire-wrap pin provides an array of test points to facilitate troubleshooting — an important factor in the achievement of low cost diagnostic.

Receiver Characteristics

As mentioned previously, receiver design and electronic components have undergone major improvements in the past few years. Some of these improvements, as well as some standard techniques have been incorporated into the design of the CEI general-purpose receiver. They include:

- (1) triple conversion to provide maximum control of spurious mixer responses, image frequency rejection, and IF frequency rejection (see Figure 1),
- (2) extended input frequency range to 5 kHz,
- (3) multipole crystal filter following each conversion for optimum selectivity and passband stability (see Figure 8),
- (4) low distortion, two-watt line audio power,
- (5) high resolution, signal strength meter.

High-Volume Production

While many conventional receiver modules are constructed entirely by one individual, the WJ-8718 modules travel to several stations before completion. At each station, components are inserted into oversized holes in the printed circuit board. The oversized holes not only speed up the component insertion procedure, but also facilitate extraction of components if maintenance is required. Component leads are soldered with a wave soldering machine and automatically clipped with a rotating blade. This type of high-speed production produces completed printed circuit boards much faster than conventional assembly lines using the same number of personnel.

Automatic Testing

High-volume production, such as is involved in the manufacture of a general-purpose HF Receiver, necessitates the utilization of automatic testing equipment for modules as well as for the main chassis. An automatic printed circuit board tester is used which is capable of component-level tests and verification of analog and digital circuit parameters. Faulty component locations are automatically identified, and the pertinent information is printed out so that the necessary repairs can be made.

The module troubleshooting arrangement consists of a microprocessor-based, system controller/analyzer, which is augmented by both solid-state memory and floppy-disk memory. The testing procedure is accomplished by the performance of a preprogrammed set of tests that take place through a vacuum-actuated "bed-of-nails" which makes contact with each circuit node. This singular procedure makes it possible to component-test a printed circuit board in a few seconds.

Functional testing of the printed circuit board can be executed if the

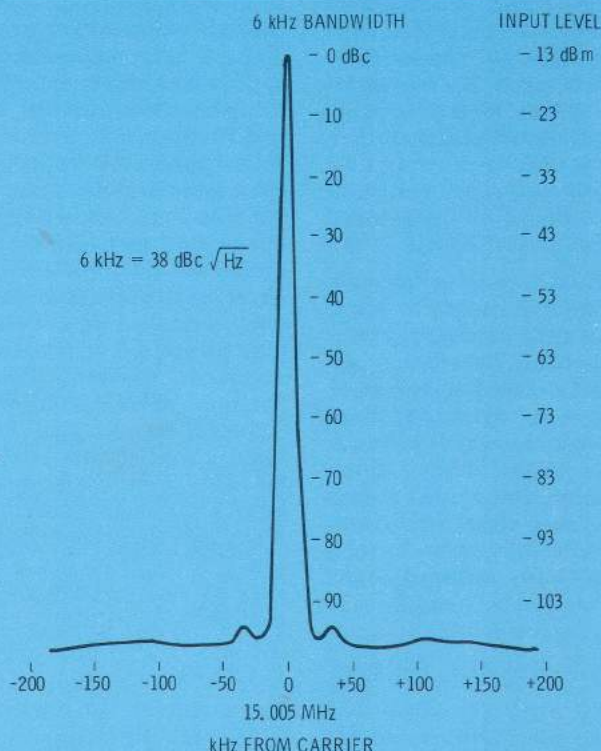


Figure 8. A multiple filter following each conversion provides optimum selectivity and passband stability.

test signals are less than 1 MHz in frequency. Modules of higher frequency are tested by masking all pins except those leading to the power supply and control lines. Module troubleshooter test equipment is then connected to the inputs and outputs, thus allowing automatic verification of the module transfer function. The operator steps through the tests manually, and reads the results on a viewing screen along with pass/fail verifications.

Functional testing, even when manually executed, takes only a few minutes (including adjustments) per printed circuit board. Failure data for each module is logged into a memory bank, and is used to detect failure mode trends in components.

The main chassis is tested using a printed circuit test board which, when plugged into four different locations, will give a lamp indication if all voltages are correct. All modules are operated while in the main chassis for a burn-in period of 96 hours at 50°C.

After the burn-in period, the receiver is connected to an automatic diagnostic test set which operates similarly to the module tester, except that it utilizes a "bed-of-cups" that makes contact with wire-wrap type pins located beneath the mother boards. A sequence of tests is then automatically performed to detect any module failures that occurred during the burn-in period. Receivers which pass the automatic diagnostic test are reconfigured for final test.

The final receiver test is performed using automatic test equipment controlled by an HP-9825 computer. A special IEEE-488 type remote interface printed circuit board is temporarily plugged into the I/O section of each receiver. All connections between computer, test equipment, and receiver are controlled by the general-purpose interface bus (IEEE-48).

The HP-9825 exercises the receiver through twenty-three separate tests, while automatically measuring the receiver's outputs. A final test print-out is produced showing all test parameters and final test data. The final test procedure is an extremely efficient test method, which reduces three hours of manual testing to a few minutes. This array of automatic test equipment and procedures is also used to repair any units returned from the field.

New Designs

In the past few years, HF Receivers

have undergone radical design changes, mainly because of the need for higher dynamic range and remotely controlled applications. As it becomes necessary to replace older receivers, it is generally true that remotely controlled state-of-the-art receivers containing synthesized local oscillators may cost five to ten times more than the original cost of the receivers which they replace. To deal with the problem of escalating costs, general-purpose receivers that have several remote control options may be utilized to replace a variety of outdated receivers. The Watkins-Johnson CEI Division's WJ-8718 HF Receiver is one such receiver. The basic layout of the receiver is dominated by EMI requirements as well as convenient remote-control capability. Many of the economical aspects of the receiver were brought about not only by high volume production, but also by cost reductions in fabrication, assembly, testing, and material purchasing.

Authors:



Charles E. Dexter

Mr. Dexter is a member of the Watkins-Johnson CEI Division technical staff. He is the program manager for the WJ-8718 HF Receiver, which is a high-volume version of the WJ-8888 HF Receiver. Previously, Chuck was a member of the CEI Advanced Development Section, where his responsibilities included development of frequency synthesizer techniques designed to

improve spectral purity and the production of more effective synthesizers.

Before joining the Advanced Development Section, Mr. Dexter was Head of the Frequency Counter and Synthesizer Group and was responsible for the design of frequency counters, frequency extenders, and surveillance receiving systems. Major design activities were directed toward designing frequency synthesizers and digital control of the WJ-8888 HF Receiver and frequency synthesizers for the WJ-9085 Tuner and the WJ-8940 EMI measuring system. The frequency range of these synthesized receivers range from 0.5 to 1000 MHz. Major products developed by Mr. Dexter's group include the DRO-280A and the DRO-309A Frequency Counters.

Mr. Dexter holds a B.S.E.T. degree in applied science from Capital Institute of Technology and is an associate member of IEEE.



Robert D. Glaz

Mr. Glaz is Head of the Watkins-Johnson CEI Division's HF Receiver Section. He is responsible for the initiation, development and production of all products within the HF range. The WJ-8718 and WJ-8888 are the major products in his product line.

Since February, 1976, he has been the HF Product Line Manager, coordinating all activities within the division, to ensure the growth of the HF Receiving Section. His responsibilities in this area include proposals, marketing, budgets, schedules, product quality and costs.

From June, 1969 until September, 1973, when he assumed primary pro-

ject responsibility for the WJ-8888, a state-of-the-art digitally-controlled HF receiver, Mr. Glaz was Head of the VHF/UHF Receiver Section. This section developed such standard catalog items as the WJ-8730 Receiver, the initial manpack receivers and the Type 565 VHF/UHF Receiver.

Prior to this, he served as a Senior Electronics Engineer specializing in receiver design and development. The RS-180 System, a miniature twelve channel VHF/UHF receiving system using a time-shared counter with DAFC was completed under his leadership. He was responsible for the development of a five-band, remotely-tuned, monopulse tuner system that operates from 150 MHz to 4 GHz and designed the tuners from 150 MHz to 1 GHz and the control units. He was also responsible for the design and development of manual VHF and UHF dual channel receivers for the FLR-12 system. Other development projects include wideband tuner development using nuvistors, bipolar and field-effect transistors, and special purpose surveillance receivers.

Mr. Glaz holds a B.S.E.E. degree from Polytechnic Institute of Brooklyn.

WATKINS-JOHNSON CO.
PALO ALTO, CALIFORNIA

BULK RATE
U.S. POSTAGE
PAID
PERMIT NUMBER
7577
SAN FRANCISCO
CALIFORNIA



WATKINS-JOHNSON

Manufacturing
and Office Locations

United States

SALES OFFICES

CALIFORNIA

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

Watkins-Johnson
831 South Douglas Street
Suite 131
El Segundo 90245
Telephone: (213) 640-1980

DISTRICT OF COLUMBIA

Watkins-Johnson
700 Quince Orchard Road
Gaithersburg, Md. 20760
Telephone: (301) 948-7550

FLORIDA

Watkins-Johnson
325 Whooping Loop
Altamonte Springs 32701
Telephone: (305) 834-8840

MARYLAND

Watkins-Johnson
700 Quince Orchard Road
Gaithersburg 20760
Telephone: (301) 948-7550

MASSACHUSETTS

Watkins-Johnson
5 Militia Drive
Suite 11
Lexington 02173
Telephone: (617) 861-1580

NEW JERSEY

Watkins-Johnson
90 Monmouth Street
Suite 207
Red Bank 07701
Telephone: (201) 842-2422

OHIO

Watkins-Johnson
2500 National Road
Suite 200
Fairborn 45324
Telephone: (513) 426-8303

TEXAS

Watkins-Johnson
9216 Markville Drive
Dallas 75243
Telephone: (214) 234-5396

International

ITALY

Watkins-Johnson Italiana
S.p.A.
Piazza G. Marconi, 25
00144 Roma-EUR
Telephone: 59 45 54
Telex: 63278
Cable: WJROM-ROMA

GERMANY, FEDERAL REPUBLIC OF

Watkins-Johnson
Manzingerweg 7
8000 Muenchen 60
Telephone: (089) 836011
Telex: 529401
Cable: WJDBM-MUENCHEN

UNITED KINGDOM

Watkins-Johnson
Shirley Avenue
Windsor, Berkshire SL4 5JU
Telephone: Windsor 69241
Telex: 847578
Cable: WJUKW-WINDSOR

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.