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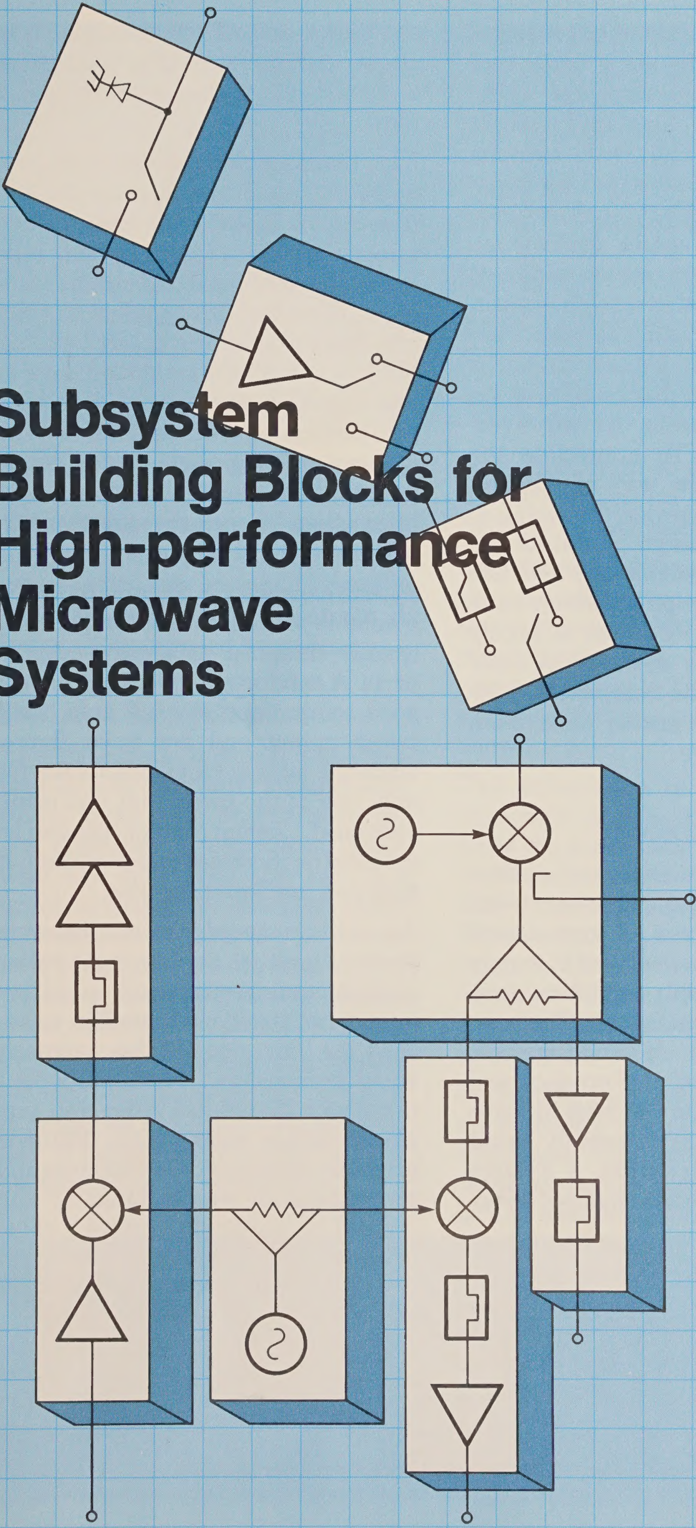
Subsystem Building Blocks for High-performance Microwave Systems



WATKINS-JOHNSON COMPANY

Tech-notes

Military airborne systems have always been constrained by the quantity and complexity of the microwave equipment on board. Size and weight requirements, along with extreme environmental stresses, put an upper limit on the capability of such systems. As technology advances, systems are able to grow more complex and meet more requirements. In fact, changes in design approach and available tools for system designers are presently increasing the capabilities of systems under development at an ever-increasing rate. To appreciate the impact of the new way of building systems, one must review the evolution of approaches to designing state-of-the-art microwave systems. The field has gone through three progressively more advanced stages in design of highly complex airborne systems. A brief explanation of the component, subsystem, and integrated subsystem approaches follows.

Component Approach

One way to build a microwave system is to purchase and put components together. An array of component manufacturers has matured to supply system builders with amplifiers, oscillators, mixers, switches, etc. They can be used to build electronic warfare systems with good performance and reliability, and many of these systems are deployed or are currently being designed. For example, a system designer who needs low-noise down-conversion and a filtering unit, such as shown in Figure 1, looks in catalogs for a low-noise amplifier, a mixer and a filter.

Lead times are short, products are relatively inexpensive and, since the system can be broken between any two components for testing, system integration is facilitated. Therefore, turnaround time for a design is fast and risk of a disastrous failure in any building block is low. There are advantages to this approach, but none of them concern performance, which turns out to be the sum of component values minus degradation due to interfaces and interactions between the various pieces of the system.

System capability is determined by the available performance of components, usually designed as general-purpose parts. A catalog amplifier may have a good compromise of high gain, high power output and low noise figure, while the system requirements are for only one of the three, that one being very good. Custom components can be specified for increased performance, but then cost and lead-times rise.

As system requirements become greater, both in quality (e.g., better system sensitivity) and quantity (number of functions needed in a system), the limitations of this approach show themselves. Each component takes up a designated space and supplies a certain weight. Each demands attention from the system designer and the technician who is building and

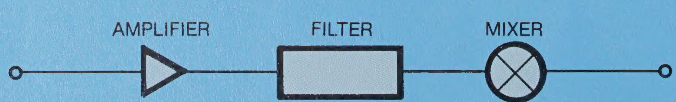


Figure 1. Part of an ECM system made from components.

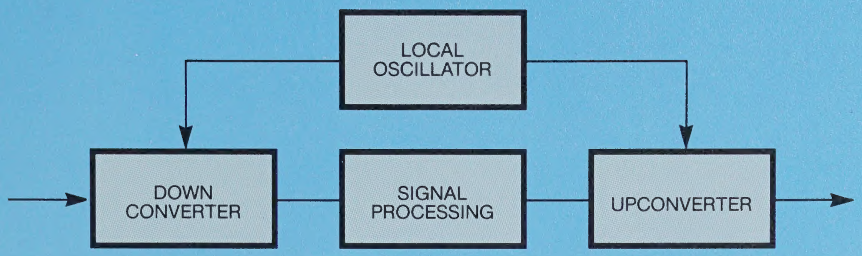


Figure 2. An ECM system made from subsystems.

aligning the system. Connectors and interconnection cables are necessary. Mechanical support must be supplied, and this becomes complicated for large systems with interconnects. Generally, electrical performance is subject to mechanically imposed limitations.

What Is A Subsystem?

The subsystems approach has come about because microwave systems have evolved to the point where the component approach is sometimes inadequate. The subsystem approach is a logical extension of the component approach; it breaks the problems involved in the design of a large system into more manageable sets of subsystem and interface problems.

In the subsystem approach, the system is divided into functional blocks, which are integrated into a total system. Each block is responsible for some identifiable function or set of functions.

Figure 2 shows a simplified ECM system block diagram. The system includes a downconversion block to transform microwave signals to a lower IF frequency, a processing block where the signal is analyzed and used to reconfigure the system output to accomplish the required deception, and an upconversion block to reconvert the signal to microwaves and boost its power for return to the threat source. Systems in general may be similarly broken into subsystems.

Each system building block can be one or more subsystems, depending on its size and complexity. An example of a current subsystem, the WJ-C80 converter, is shown in Figure 3. The block diagram for the subsystem is also shown.

The subsystem is constructed of standard and specially designed parts combined into a single building block for a radar system. The product has switches, several amplifiers, filters, a mixer, an attenuator and an isolator, along with controlling electronics. To the system designer, the whole subsystem is just a single, useful block.

Each subsystem has its own integrity: all necessary circuitry is part of the subsystem, and circuitry not germane to the operation of the particular block is not included. The division of the system into blocks introduces a structure to the system, much as writing subroutine structures for a computer program. System design is made easier and more logical by imposition of the subsystem structure.

Interactions between subsystems occur only through specified input and output paths. The designer can

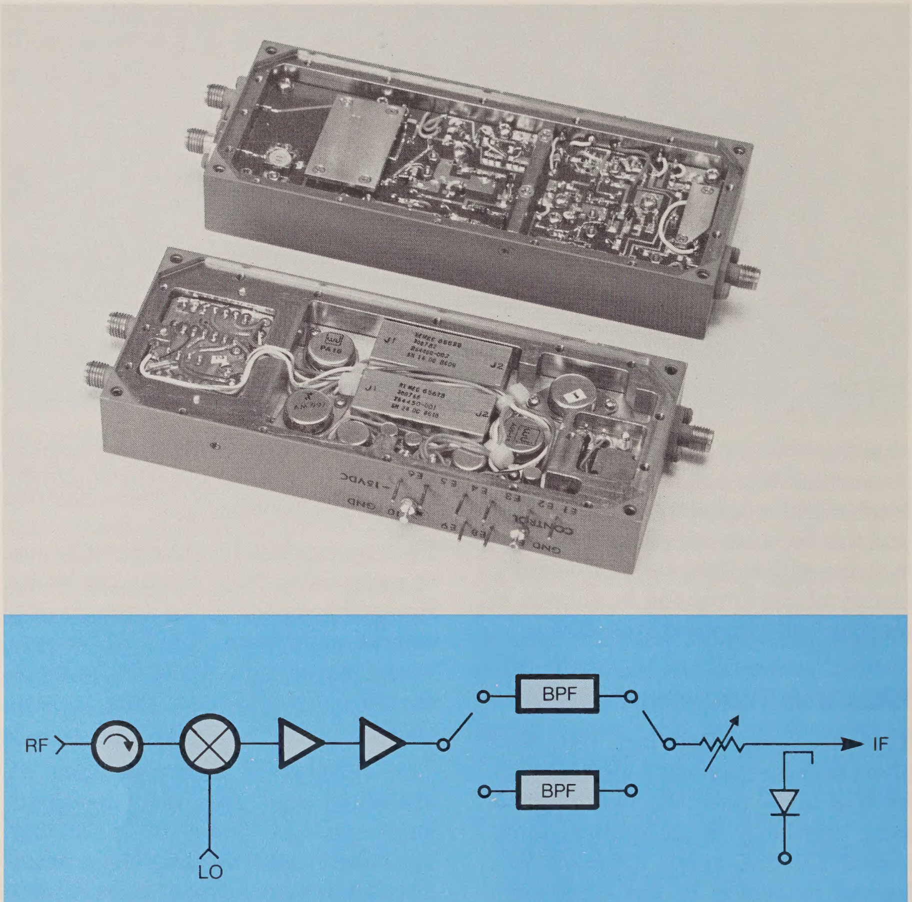


Figure 3. An airborne radar converter subsystem. The unit is assembled from standard and specially designed parts.

concentrate on the function of a particular subsystem and vary the specifications with predictable results and minimal disturbance to the other blocks. In this way, the system design can be arrived at by successively iterating the performance of the various subsystems. In this process of converging on a system design, the actual blocks used as subsystems evolve and change as performance trade-offs between blocks are investigated.

Within a particular block, the subsystem designer is allowed maximum freedom to pursue the design. He can take advantage of the freedom allowed by a functional specification to make component performance trade-offs within the block. There are no unnecessary constraints imposed inside the subsystem by the system designer: his concern is with the inputs and the outputs to the subsystems, and he is satisfied as long as their specifications are met.

The designer of the subsystem faces the same choices of how to build the unit as does the system designer, only on a smaller scale. As mentioned above, the subsystem's complexity may range from several components to a complicated assembly in itself. The designer can buy components if they will fit,

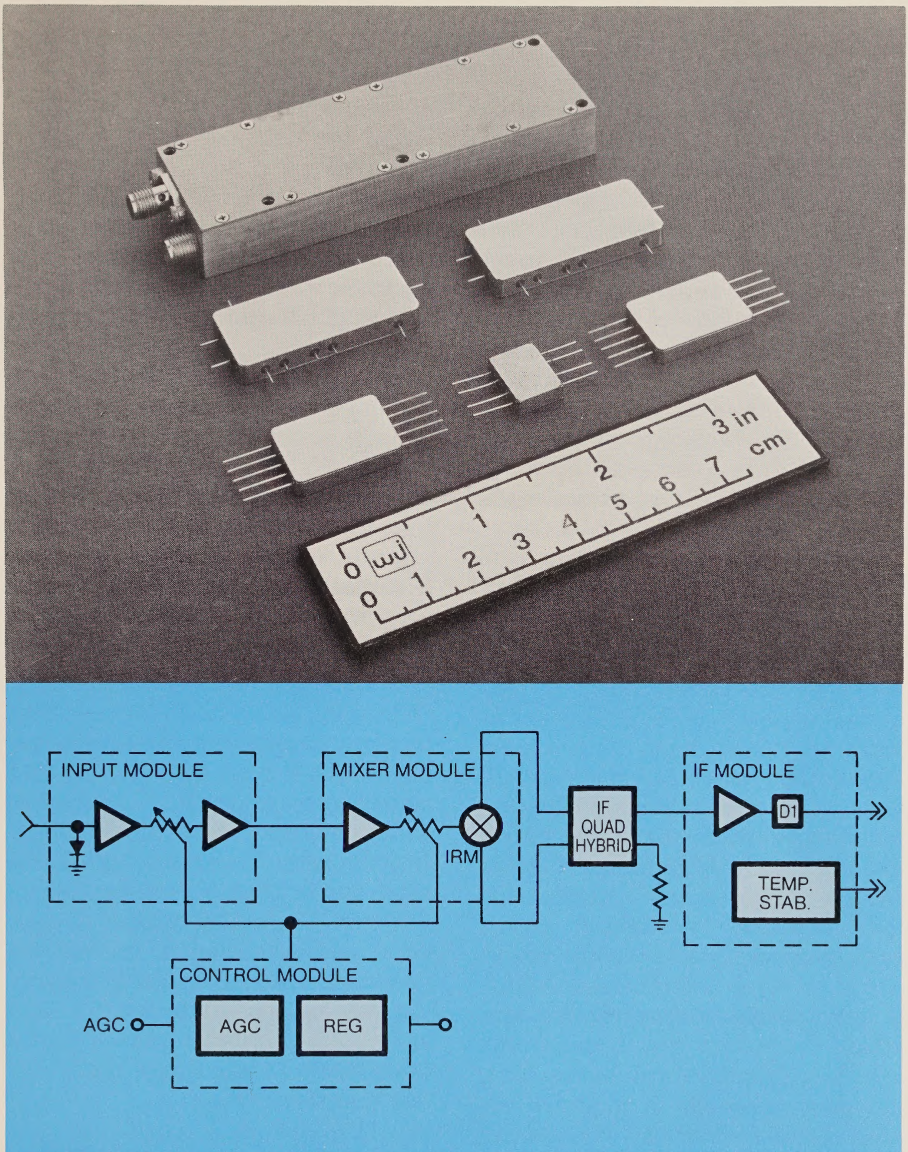


Figure 4. A downconverter subsystem comprising several smaller subsystem building blocks.

design components, or do a combination of both. In fact, if the subsystem is large, it may, in turn, be broken into smaller subsystems. Figure 4 shows another downconverter subsystem with its corresponding block diagram. This subsystem is built from a modular combination of smaller subsystems. The unit is a preamplifier/downconverter used in an X-band data link. It has a low-noise preamp and a thin-film image-reject mixer. This type of converter is used in applications where low noise-figure performance is a prime requirement.

The specification of a subsystem transfers some of the more difficult mechanical and electrical problems from the system designer to the subsystem designer. Another level of design has been introduced and some of the challenge of the system design can be met at that level. The result is to replace an overwhelming number of system decisions with a smaller number of subsystem decisions, with each subsystem decision affecting only the block under consideration. This facilitates design of more complex systems than the component approach. Since each subsystem is significantly smaller than the system, and the system mechanical design can concentrate on a rugged assembly of subsystems, the large system made from subsystem building blocks is generally a more durable configuration than a system that is assembled from separate components.

The investment involved in designing a subsystem is considerable. The subsystem approach is dictated by one of three situations. First, high-volume applications justify the initial expenditure by production savings. Second, the requirements are impossible to meet by assembling components without regard to clustering them into subsystems because of weight or volume limitations, or because of some critical specification (e.g., gain flatness). A third case where subsystems are indicated is when there is a requirement for significant-sized logical blocks (e.g., systems designed in modules for maintenance). Usually, the second of these reasons is what drives subsystem requirements.

Miniaturized, Highly Integrated Subsystems

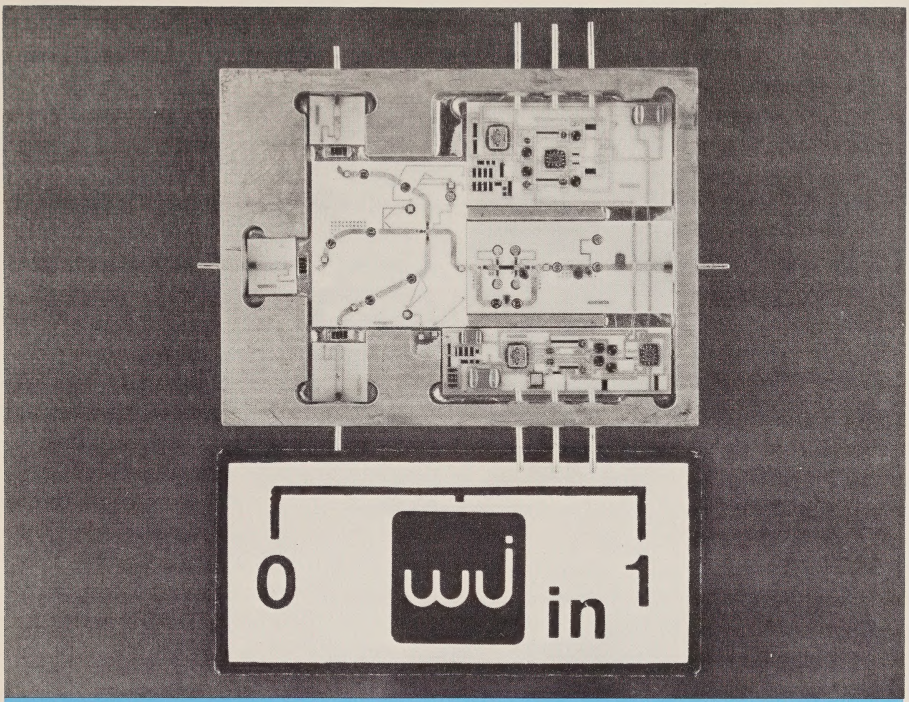
Subsystems like those described above are optimal for an extremely wide range of system requirements. The bulk of current subsystem production falls in this category.

However, partly because of the success of the subsystem approach to filling system requirements, airborne, missile and expendable systems are experiencing increased need of very rugged, lightweight and highly complex subsystems. Because of advances in design and manufacturing technology for microwave components, radar and electronic warfare functions previously not candidates for these applications are now within reach. Highly miniaturized modular subsystems are changing the capabilities of these systems by increasing performance and reliability in extremely small physical volumes. Newer subsystems have recently started to show up which are different enough to warrant a new classification of subsystem: the hybrid integrated subsystem.

The hybrid integrated subsystem is a departure from earlier approaches. Originally, subsystems were bolted-together components. Newer requirements tend to have space, weight and performance constraints so severe that stand-alone components are a liability. In some cases, the module itself is not much larger than one of the components from a catalog because of creative design and savings in "mechanical overhead." Instead of putting together discrete components to form a subsystem, the designer makes many components in one single, multifunction electronic module.

Figure 5 shows an inside view of a receiver-protect module, and its corresponding block diagram. The purpose of the module is to select one of three channels for processing in a radar system, stand off high power, and provide attenuation to prevent system gain saturation as commanded.

The module is very small, but withstands incoming power levels into the kilowatt range. The housing is made of carefully selected steel, with copper



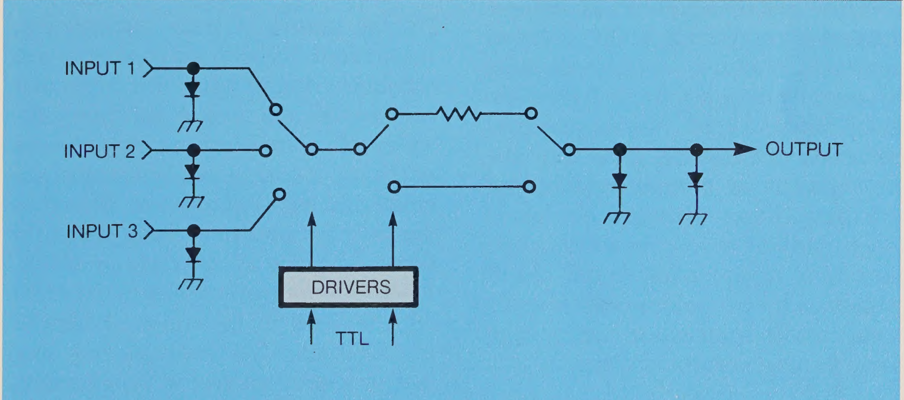


Figure 5. A receiver-protect module; an example of a single-module hybrid thin-film integrated subsystem.

heat pipes to carry off rf power dissipated in the diodes. This example is one where many materials engineering problems were encountered in one module.

The primary factor allowing the development of more challenging miniaturized subsystems is the influence of recent advances in hybrid microwave integrated circuits. Research and development is demonstrating advanced hybrid processing technology that brings complex modular microwave subsystems within realistic cost bounds. This facilitates use of larger and more powerful modules, making possible more sophisticated systems in extremely small volumes.

There are a number of areas where new technology is bringing down module cost, while facilitating modules of increased complexity. Thin-film rf resistors and capacitors cut chip and wire count in modules. Assembly and tuning labor drop significantly when these electronic features are built into a hybrid module, as compared with modules made of large numbers of discrete devices. Automated chip placement and bonding further reduce recurring module cost.

RF monolithic circuits are well adapted to integrated hybrid subsystems: an unpackaged GaAs device performs its function in an extremely small volume, and is easily dropped into an integrated hybrid subsystem. To date, there have been very few products incorporating GaAs monolithics that are not best characterized as hybrid modules.

Thermal match of materials, component attach and compatibility between materials, platings, and glasses must be specially designed for, in hybrid circuits. Sophisticated mechanical and materials engineering goes into the development of miniaturized hybrid circuitry, along with the electronic design. Advances in laser welding and carrierless design allow better use of system space by making possible subsystems with unusual geometry, compared to most current modules.

Each hybrid module in a system can be made self-sufficient, minimizing the need to pass wires and cables between modules. Analog and digital control circuitry is contained within the module. Electronics is realized in hybrid form, using either discrete or LSI chips; there is no longer a need to have a multitude of module-specific control lines entering or leaving a hybrid MIC. The large printed-circuit boards that accompany the rf section of many systems are eliminated. Modules are designed with internal voltage regulation, further reducing wire count between modules. TTL or ECL compatible inputs are supplied, and analog signals can be generated within the modules for noise immunity.

The microwave systems with the most severe size and weight requirements (missile, aircraft, etc.) also have the most extreme mechanical shock, vibration, temperature, and hermeticity requirements. This is a problem in systems built from separate components: more components means more mass and volume, and less resistance to degradation and damage on that basis. More components also means more interconnections and cables, and the *law of large numbers* dictates that this increased number of weak points decreases reliability. The larger the system, the more susceptible it is to environment damage.

By the nature of their construction, integrated hybrid subsystems are extremely rugged when compared to a comparable amount of packaged circuitry. RF connectors are only present at the input and output. Substrates are small and soldered in place. Bare dice are used for electronic chips, and held firmly in place by adhesive or solder. Electronic interconnects are bond wires with a mass in the range of tens of micrograms. The package has one hermetic weld enclosing all circuitry, the length of which is typically only a few inches. A whole subsystem's mass is measured in ounces or fractions thereof. The threat to systems from mechanical shock, vibration, and temperature cycling is in some manner proportional to mass or length, so the small size and mass of hybrid modules is primarily responsible for their increased ruggedness over larger subsystems. The integrated hybrid subsystem, while able to perform the function of several (or many) compo-

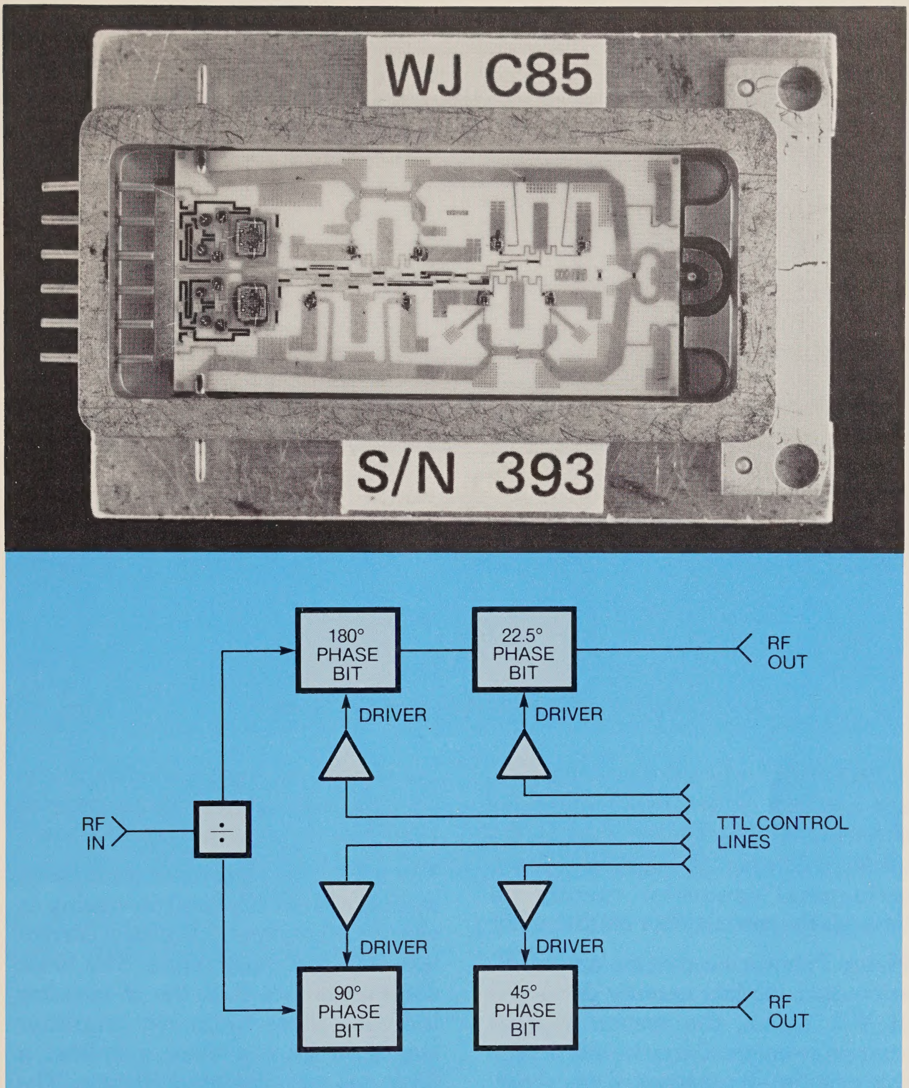


Figure 6. A power splitter/phase shifter module.

nents, is able to withstand thousands of g's of shock and constant acceleration without performance degradation.

A Look At Some Current Subsystems

Several examples will show the variety of hybrid integrated subsystems currently produced at Watkins-Johnson Company. The units span a range of function type and complexity, and all have been shown to be the optimum configuration for missile and other airborne applications.

Figure 6 shows a power splitter/phase shifter module used in a monopulse radar system for system phase-matching control. The module splits the rf line and applies two bits of phase shift to each line. This allows the full four bits

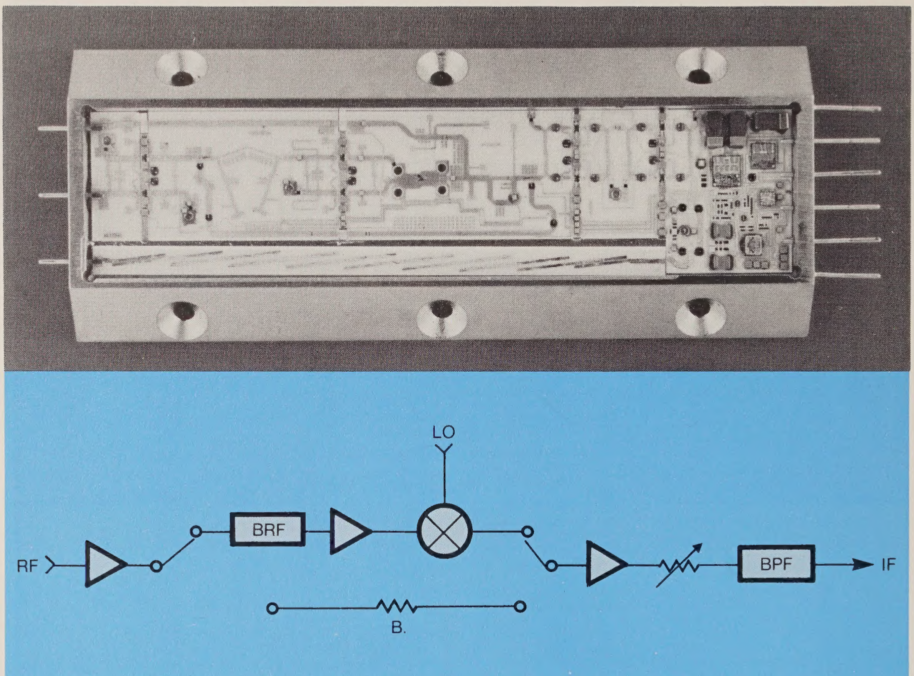


Figure 7. A single-module receiver subsystem.

of phase shift when the two channels are applied to the two monopulse channels. Of particular note is the unusual geometry dictated by the orthogonal connector coming up through the module floor on the right.

Figure 7 shows a converter/amplifier/attenuator module recently developed at W-J. Again, the system imposes strange geometrical constraints. Inside this module (all constructed on carrierless alumina substrates), are four balanced stages of gain, a mixer, several filters, a diplexer, several switches, a reflectionless attenuator, and integrated electronics to interface with TTL inputs. The module works off a single positive voltage supply and includes its own voltage regulators.

The subsystem has stringent switching speed and pin-to-pin isolation requirements as well as the usual gain and noise figure limits. In final assembly, a mechanical wall is inserted before laser-sealing the module, allowing units to be shipped within excess of 100 dB of pin-to-pin isolation at X-band.

The module in Figure 8 is a converter module with ECM signal processing as one of its functions. It is also of carrierless alumina construction. The block diagram shows that the rf circuitry includes three balanced amplifier stages, switches, a mixer, a diplexer, a filter, and some deception circuitry. The analog and digital electronics accepts TTL commands and, upon the proper signal, accomplishes signal deception. As is becoming a theme, the mechanical configuration has unusual constraints imposed. Important specifications for this modular subsystem are conversion efficiency, isolation, switching speeds, and effectiveness of the countermeasure performance.

The subsystems in Figures 5 through 8 are hermetically sealed units that withstand thousands of g's of shock

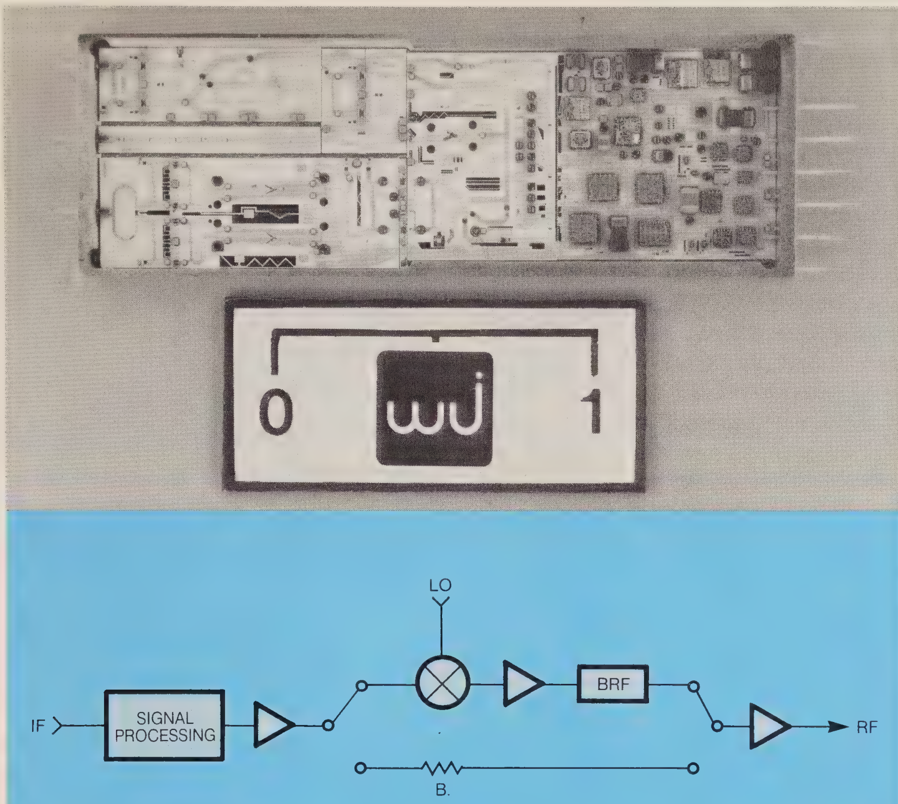


Figure 8. A converter/signal-processing hybrid modular subsystem.

in actual operation. Further advances in the areas of cost effectiveness and performance of the modules are under way.

Summary

The design of microwave systems for radar and electronic warfare applications has been a continually evolving process. In response to increasing needs, the process has gone through several stages allowing systems to evolve to greater complexity with each stage. Currently, there is an increasing need for airborne, expendable and missile microwave systems with a diverse and high-quality repertoire of functions. Presently developed subsystems are meeting these needs with reliability and ruggedness unattainable only a few years ago. Advances in several areas, including rf monolithics, promise exciting advances in the future.

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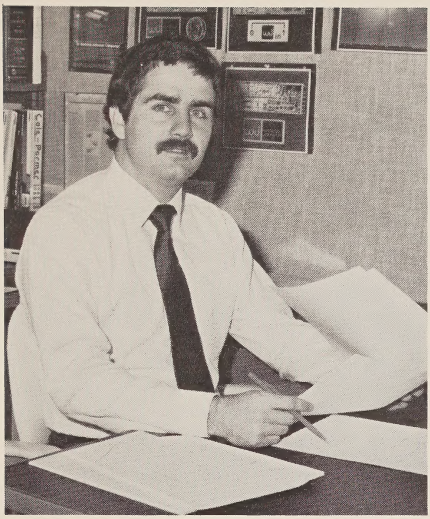

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