AN ALL SOLID-STATE MIC TRANSMIT - RECEIVE MODULE

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This paper discusses the results obtained in the design and development of two breadboard solid-state MIC transmit-receive modules; the second unit being an improved version of the first unit. Attention will be focused on both results that were obtained, and the associated problems involved in the integration of several distinct components into a single module. The associated problem discussion will deal with two areas:

1) The difference in RF boundary conditions of a single component and of multiple components integrated into a single subsystem.
2) Fabrication difficulties as they related to integrating several components.

The module under consideration was designed by Raytheon Company, Missile Systems Division, in 1969-1970. The effort was sponsored by the Air Force at Wright Patterson Air Force Base. The overall objective is to ultimately use such a module in airborne phased array communication systems.

Module Description

The goal at the outset of the program was to design a completely integrated all solid-state CW transmit-receive module in dual breadboard form. That is, the unit was to ultimately contain two receiver sections and two transmitter sections. The reason for a dual module approach stems from the interface connector requirements between the phased array aperture and feed network of the overall communications system. A dual module approach reduces the number of physical connections by a factor of two over that of a single module. Efforts during this program were carried only to the extent of fabricating one transmitter and one receiver section in the dual module encasement.

Since the main objective was for utilization in airborne systems, size and weight were parameters of utmost importance. Therefore, the medium of transmission chosen was microstrip. The microstrip medium is composed of 0.025 inch thick alumina substrate material with a chromium (Cr) - gold (Au) deposition. The two ferrite phase shifters utilize a BeO substrate in the first module and a ferrite substrate in the second module.

Figure 1 contains a functional block diagram of the T/R module. The uplink frequency modulated carrier (f_t) enters the module and passes through a phase shifter where beam steering information is applied to the carrier. This signal is then amplified with a phase-locked IMPATT oscillator configuration. A band-pass filter is then employed to remove any noise components. A circular polarizer then splits the signal into two components of equal magnitude and 90° separation for excitation of the orthogonally polarized radiating elements. The received signals are combined by the circular polarizer, then passed through a band pass filter which block any leakage from the transmitter band. A local oscillator signal is applied to the module and passed through a ferrite phase shifter in which the beam steering information is added. The received signal is then down-converted in a balanced mixer. The IF output is then amplified in the preamplifier and exited from the module. The operating characteristics of the two modules are tabulated in Table 1.

Individual Component Description

A three bit (8 position) design was used for both module phase shifters. In the first breadboard module the design consisted of a thin slab of ferrite material mounted over a meander line microstrip circuit. The insertion loss was approximately 2.3 dB and the differential insertion loss was less than 0.1 dB for different phase states. The phase shifter performance, however, was extremely sensitive to the applied pressure on the ferrite overlay; thus making it difficult to achieve reproducibility from unit to unit. As a result, a redesign was incorporated for the second module. In the new design, the meander line patterns were printed directly on a 0.025 inch thick ferrite substrate. The insertion loss of the second unit was approximately 3.0 dB with a variation of not more than 0.1 dB over the 0-315 degree range of the phase shifter.

For the circulators used throughout the module, a lumped parameter design approach was taken. It consisted of discrete inductors and capacitors, as well as mutual coupling inductors, etched on a ferrite disc. This eliminated the need for quarter wavelength transformers used in conventional circulators. Raytheon developed Samarium - Cobalt magnets were used to magnetize the ferrites. The total diameter of the circulator is 0.180 inches. Isolation of $\geqslant$ 20 dB and insertion loss $<$ 1.0 dB was obtained over an 8 percent bandwidth.

The RF amplification section of the transmitter originally was designed to consist of three phase-locked oscillators. The required performance was ultimately obtained with only two stages. In the first module, the last stage was a 1W coaxial oscillator. The lower power locked oscillator stages were fabricated in microstrip. The first stage was eventually eliminated from the design. In the second breadboard module, the coaxial 1W oscillator was replaced by a microstrip design. It became necessary to completely shield these oscillators in order to achieve an acceptable performance. Problems associated with the evolution of these shields will be expanded on in the problem discussion of this paper.

A five section 0.1 dB ripple Tchebyscheff Design was used for both filters in the module. An end coupled design approach was chosen over a broadside coupling design, because of the higher resonator Q values that could be realized. It became necessary to enclose each filter with a separate metallic cover to maintain the desired results. The insertion loss was 1.0 dB for the transmit filter with 40 dB rejection at the receiver frequency; and 1.4 dB for the receive filter with 43 dB rejection at the transmit frequency.

The 90 degree hybrid design, which separates the transmit and receive signals had an insertion loss of 0.4 dB in both the transmit and receive frequency bands. The power split difference was $<$ 0.2 dB, and the isolation was 21 dB at the receive frequency and 23 dB at the transmit frequency.

The balanced mixer uses two silicon Schottky - barrier beam lead diodes in a two branch microstrip hybrid, with resistive - terminated image bands. The IF preamplifier uses two silicon low noise transistors in a tuned circuit. The mixer-preamp has a noise figure of 8.6 dB at midband and 9.0 dB at the band edges; and a 14 dB minimum overall gain. A LO drive of +6 dBm is required.

Associated Problems

The process of design and development was divided into two stages. First the individual components were designed separately, and then the individual components were integrated into a final module design. However, the RF performance of many of the components was effected by the new boundary conditions that were established during the integration; so that a redesign became necessary. The components most severely effected were the microstrip oscillators in the transmitter and the two five-section microstrip filters. Other problem areas peculiar to the microstrip medium are concerned with mounting the substrates in such a manner as to minimize thermal expansion stresses, and RF losses in connecting substrates, and to still maintain accessibility for component replacement. The problem of accessibility in this particular design was further aggrevated by mounting the dc circuits between the RF microstrip planes along with a RF coaxial interconnecting cable.

The problem of isolating the components, namely the IMPATT oscillators and filters, and thus stabilizing the various impedance conditions could be easily solved only by physically isolating the components into separate metalized enclosures. So that in effect, the performance of the individual components was unaffected by integration into the module provided that the proper input and output impedance conditions were maintained.

In the initial design of the first and second oscillator stages, each oscillator was designed on separate substrates. After each unit successfully met the performance specifications, the two stages were combined on a single substrate with two ferrite circulators. Subsequent evaluation revealed the existence of excessive cross coupling above the substrates as well as through the substrate material itself. It became necessary to surround each oscillator-circulator combination with side walls which extended through the substrates down to the ground plane. In regard to the upper boundary condition, the operating frequency, output power, and Q were also sensitive functions of the main module cover. Therefore a separate brass cover was incorporated over the two oscillators. This same approach was utilized in the fabrication of the second module.

The same type of difficulty was encountered in integrating the two microstrip filters into the module. The two filters were successfully designed on individual substrates; and upon integration into the module the performance, in particular the pass-band ripple, was significantly degraded. The filters were redesigned with each one having its own tunnel like cover.

Due to the high degree of thermal dissipation of required for the oscillators, a compatible carrier plate was required to minimize thermal stress. Kovar was chosen as a suitable carrier. The substrates were soldered to the Kovar carrier and the carriers fastened to the main frame. This process was only implemented in the second module.

Another difficulty in utilizing the microstrip medium is its inherent resistence to modifications. Once all the substrates were bonded into place, it became difficult to make individual component modifications without either breaking or disturbing adjacent components. This problem was further complicated in this design because various dc-components and an RF transition were imbedded between the microstrip planes.

In summary, the microstrip medium, although offering many advantages still has its drawbacks especially @ X-band and above. It is difficult to realize high Q components, high components isolation, and thus very low loss systems. In order to improve some of these characteristics it is necessary to compromise on component accessibility by enclosing individual components. Thermal expansion compatibility can be obtained only by incorporating additional weight in using the heavy Kovar metal as a subcarrier.

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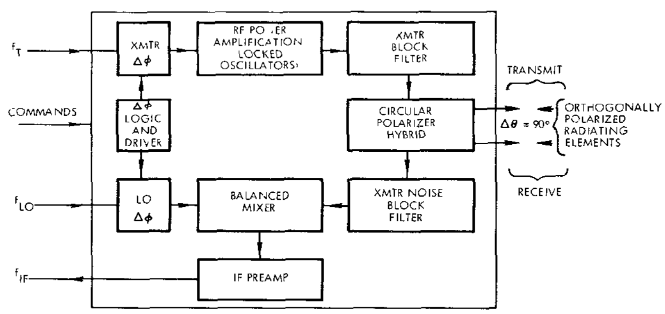

FIG. 1. FUNCTIONAL BLOCK DIAGRAM OF MODULE

TABLE I

OPERATING CHARACTERISTICS OF THE T/R MODULE

Transmitter Frequency	In Uplink Band (7.90 - 8.40 GHz)	
Receiver Frequency	In Downlink Band (7.25 - 7.75 GHz)	
Transmitter	1st Module	2nd Module
Exciter Input	5 mW	5 mW
Output at each Output Port	90 mW	100 mW
Locking Bandwidth	120 MHz	60 MHz
Deviation from Linear Phase for 10 MHz Bands	$<10°$	$<10°$
Receiver		
IF (500 MHz) Noise Figure	11.1 dB	10.7 dB