THE SELECTION OF HIGH-POWER INTEGRATED MICROWAVE COMPONENTS FOR MILITARY SATELLITE COMMUNICATION TERMINALS

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Abstract

This paper describes a program to optimize the performance of a high-power broadband satellite communications klystron by selection and interfacing a chain of microwave components between the tube and antenna. Tests results are given for the 7.9 to 8.4 GHz military satellite communications band.

Introduction

Discussions were held between personnel of the Naval Research Laboratories (NRL) and Varian Associates, Inc. regarding ways to improve performance of military satellite communication (SATCOM) systems. From the Navy's standpoint, it was deemed essential that the individual output component specifications be combined at an early stage so as to control the overall system performance prior to final system assembly.

It was concluded that improperly designed interfaces between power amplifier tubes and output waveguide components as well as interfaces between individual components have a large influence on overall efficiency and performance. It was also felt that in the past insufficient attention had been paid to interfacing of discrete components of a subsystem.

Therefore, interim system specifications were set and a program was defined wherein a high-power broadband klystron and associated output waveguide components would be developed and tested together to demonstrate very high performance while achieving optimum output power with varying load conditions. This report summarizes the results.

I. Technical Considerations

The first Task was to define what necessary components and functions would be required between the amplifier tube and the antenna input.

A. Arc Sensing

For high-power operation an optical arc sensor and a reflected power sensor mounted at the output of the power amplifier tube were considered essential. These devices would protect the tube from window failure due to waveguide arcs. They should respond to an arc within a very few microseconds and have fail-safe/fault-test features.

B. Isolation

It was considered essential that control over load impedance be maintained assuring maximum klystron bandwidth flatness in amplitude and in phase. To achieve this, the load VSWR (any phase) as seen by the tube was required to be 1.1:1 or less. It was known that the antenna load VSWR could be as bad as 1.3:1. This VSWR, when combined with the mismatches presented by the components between the antenna and isolator, required the use of a properly terminated four-port differential phase shift circulator with high isolation and exceptionally low input VSWR.

C. Filtering

Two forms of extra-passband filtering were needed. The 7.25 to 7.75 GHz receiver band must be protected from transmitter emissions whether spurious or of the intermodulation distortion variety. A multicavity bandpass filter was required to provide at least 60 dB attenuation.

A second filter was required for harmonics, with a minimum required attenuation of 40 dB in the second and 30 dB in the third and fourth. The overall system harmonic output (including the klystron amplifier and filters) had to be a minimum of 60 dB below the carrier (dBc).

D. Switch/Dummy Load

A desired feature of this high-power system is the ability to operate the power amplifier at full power, for test purposes, without radiating radio frequency (rf) energy. A waveguide switch with a high-power water load is required. Features of these two components are to include remote electrical switching with manual override, interlocking contacts to prevent switching under power, and a compact, reliable, leak-proof water load.

E. Waveguide Pressurization

Although not required for peak-power breakdown, the addition of a window permits use of a slight gaseous pressure which will protect the waveguide against corrosion and intrusion of foreign materials.

II. Results Achieved

A. Building Block — VUH-8426

The basic component upon which new design work was initiated revolved around the Varian VUH-8426 integrated component. This device was originally designed for use in the U.S. Army medium and heavy terminals in connection with the Defense Satellite Communication System DCSC-2 communication satellite. Elements of this component are a four-port circulator, arc sensor, coupler and terminations. Perhaps the most important feature of this device is the reduction of a 1.5:1 any phase load VSWR to 1.05:1 or less with a minimum of 26 dB isolation.

B. VUH-8460 Integrated Microwave Component

A decision was made early in the program to integrate the individual components by means of flanges. It was also considered essential that the assembly be tied to a plate in order to provide support, rigidity and ease of system installation. Water coolant tubing designed for only one water inlet/outlet was required. A supported flex-guide input was also provided. Figure 1 is a photograph of the completed VUH-8460.

In defining insertion loss it was necessary that the assembly provide a minimum output power of 2 kW for an input level of 3 kW. Thus the allowable insertion loss was 1.75 dB, although a substantially lower value was predicted and subsequently achieved. (Figure 2)

The maximum insertion loss at the low end of the band was very close to 1.0 dB but ran 0.75 to 0.9 dB over most of the band. The input VSWR across the passband is for the most part a function of the isolation between the input and any load mismatches. Figures 3 and 4 show the measured VSWR at the input with a 1.3:1 load of random phases. The maximum passband VSWR was less than 1.06:1. It should be noted that input hybrid VSWR greatly affects the out-of-band results. The bandpass filter also reflects a short circuit to the isolator on both sides of the 7.9 to 8.4 GHz passband.

Measured harmonic attenuation within the filter was greater than 50 dB in the second and third, with 33 dB in the fourth harmonic. Considering the klystron harmonic output in addition to filtering, the entire system had harmonic output 80 dB or more down from the carrier.

Raw data for group delay is shown in Figure 5. Analysis of this data over a 500 MHz and a 50 MHz lower band-edge portion of frequencies has been done to extract the components of group delay. The outcome of this analysis is as follows:

	500 MHz Band	50 MHz Band
Linear Component	0.00172 ns/MHz	0.0586 ns/MHz
Parabolic Component	0.000072 ns/MHz^2	0.000256 ns/MHz^2
Ripple Component	1.44 ns pk/pk	0.154 ns pk/pk

Finally, the high-power test data for the VKX-7780W1 klystron and the VUH-8460 output circuit are shown in Figure 6. The power output of 2.6 kW cw was seen at the output flange of the waveguide assembly and this power-out is plotted as a function of frequency for both the matched load condition and with a load VSWR of 1.3:1. Amplitude flatness and stability are extremely good with large load variation.

Other tube operation parameters and performance data are also shown.

III. Conclusions and Summary

Upon completion of this development project and a review of the test data, it is clear that some of the interim specifications should be modified.

Insertion loss specifications for this and similar output circuits can now be reduced with confidence to 1.4 dB or less, and VSWR can be reduced to the desired maximum of 1.1:1 from 1.13:1. Insertion loss variation can be defined more accurately by considering how the entire network is terminated, that is, 0.25 dB maximum over any 50 MHz when terminated in a flat load, or 0.4 dB maximum when terminated with a 1.3:1 load.

Finally, it can be concluded that the success of this program is due to the philosophy of keeping the system simple and to tuning the waveguide output circuit as a discrete component.

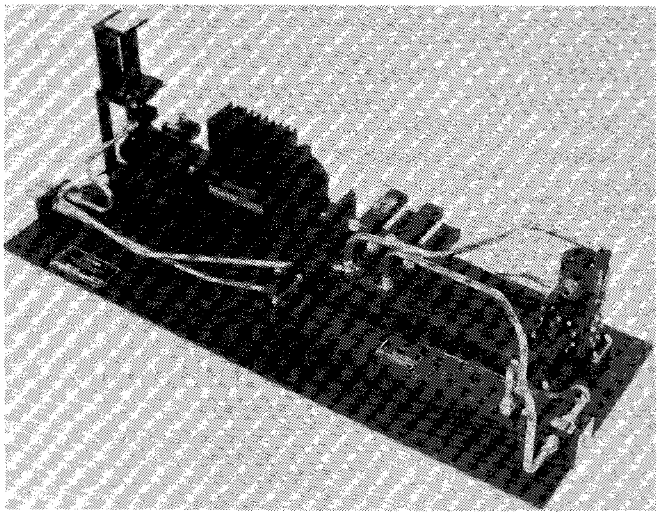

Figure 1. The VUH-8460 IMC

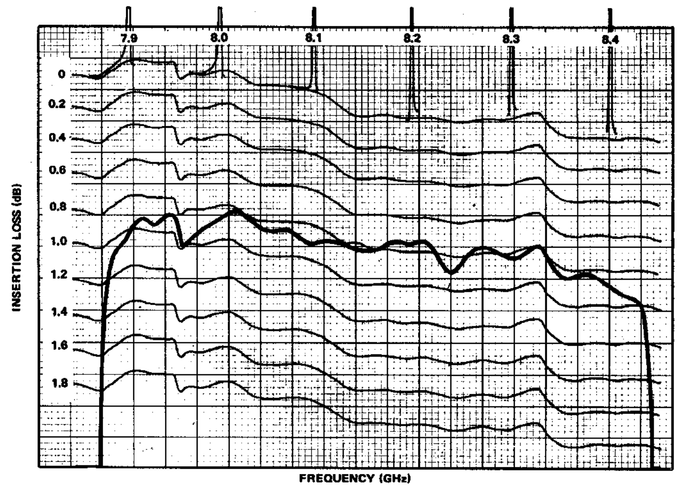

Figure 2. VUH-8460 Insertion Loss

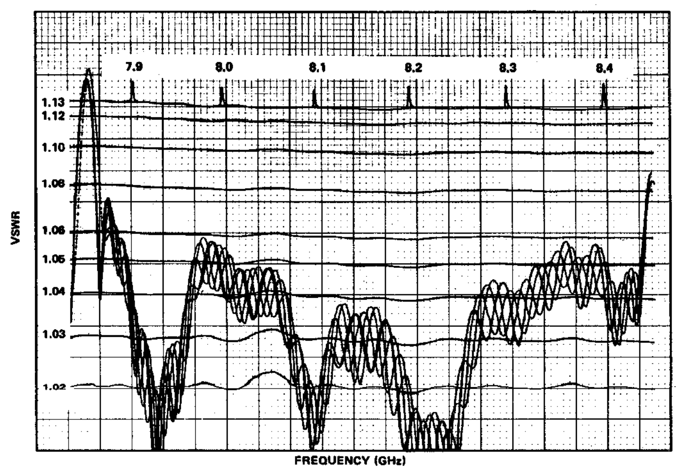

Figure 3. VSWR, (1.3:1 Load, Various Phases)

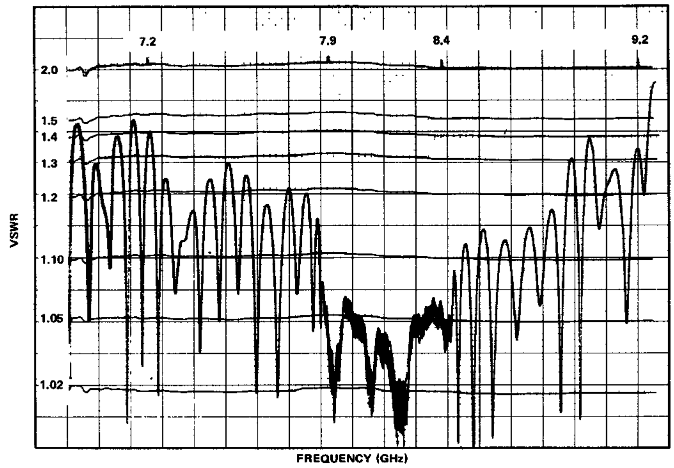

Figure 4. VSWR, Extended Band (1.3:1 Load, Various Phases)

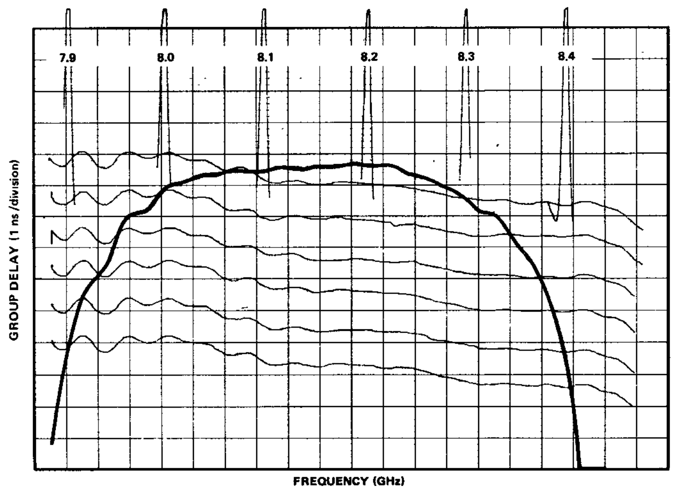

Figure 5. Group Delay

1.3:1 VSWR – 7780W-1 SERIAL NO. 142 – CHANNEL 8000

FILAMENT VOLTAGE	6.0 V	BEAM VOLTAGE	8.8 kV	POWER OUTPUT	2.6 kW
FILAMENT CURRENT	5.6 A	BEAM CURRENT	.88 A	DRIVE POWER	90 mW
MAGNET CURRENT	PM Focused	BODY CURRENT	13 mA	GAIN	44.6 dB

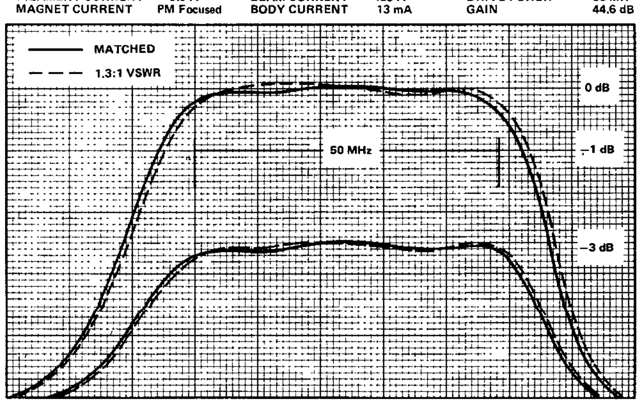

Figure 6. Power Output of Entire System including the VUH-8460 IMC and the VKX-7780W 1 3 kW Klystron