A HIGH POWER LOW PASSIVE INTERMODULATION (PIM) UHF DUPLEXER FOR SPACE APPLICATION

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ABSTRACT

This paper describes the development of a high power, low passive intermodulation (PIM) UHF duplexer to determine the feasibility of such a unit for space application. Tests carried out on the final prototype model demonstrate low loss, high power handling in vacuum (>200 watts) and low PIM - thus establishing it as a candidate design for the multi-purpose UHF satellite currently under consideration by the Canadian Government.

INTRODUCTION

This paper describes the work that was carried out to determine the feasibility of a high power, low loss and low PIM UHF duplexer for possible application in a multi-purpose satellite (MUSAT) program currently under consideration by the Canadian Government. Such a unit is considered to provide an alternative to a separate transmit and receive antenna subsystem resulting in possible weight savings. The key requirements of such a duplexer are its power handling capability in vacuum currently expected in the 200 watt range and low PIM products in the receive band which must be of the order of -150 dBm to provide adequate protection for the received signal. These goals along with low loss were achieved in the final unit, results of which are described in the remainder of this paper.

DESIGN OBJECTIVES

Based on overall system considerations, the design goals that were established for the performance of the duplexer are described below:

Passband	370 - 406.1 MHz receive 274.6 - 286.2 MHz transmit
Insertion Loss	<0.5 dB for either channel
Isolation	
Receive Channel	>60 dB at 310 and 480 MHz >120 dB at 290 MHz
Transmit Channel	>60 dB at 250 and 320 MHz >140 dB at 370 MHz
Power Handling Capability of Transmit Channel in Vacuum	>150 watts CW
Passive Intermodulation	19th order product to be <-150 dBm with two 50 watt carriers
Operating Temperature Range	-25°C to +75°C

LOSS AND POWER HANDLING CONSIDERATIONS

For space application, handling of high power under vacuum environment is a major consideration in the design of filter networks. The limiting phenomenon is 'multipaction' which takes place under vacuum conditions only [1-4] as described in Fig. 1A. For RF voltages, the multipactor mechanism becomes effective when the mean free path is of the order of the electrode spacing or greater - as described in Fig. 1B. Based on these considerations, one sees three possible ways to counteract multipactor breakdown:

(1) Pressurize and seal the unit with some inert gas.

(2) Use of low loss, low dielectric constant and light weight material to fill the unit.

(3) Choice of appropriate dimensions to prevent multipactor for a given level of peak voltages.

There is little to be said about pressurization. It is completely effective but requires extreme care in sealing the unit to prevent leaks. Connectors would require a custom design incorporating a hermetic seal. This may pose special problems to achieve low PIM. Consequently, this method is costly and spacecraft customers as well as suppliers generally tend to be apprehensive about this approach.

Use of foam material as a filler tends to degrade the unloaded Q of the filter and adds weight. In addition, the design must incorporate ways to vent any outgassing of contaminants to prevent ionization breakdown.

Choice of appropriate dimensions implies bigger volume to handle higher powers. This also yields higher Qs but the penalty is that of increased weight and volume. Increase in weight is partially offset by the lower losses and hence lower power requirement and weight of the power subsystem.

Based upon these considerations and experimentation with elementary units, filters with 2.0 inch ground plane spacing in an inter-digital structure were selected for both the receive and transmit channels. In addition, the input and output coupling probes require a considerable design effort to ensure protection against multipactor breakdown and at the same time to achieve lowest possible PIM. Fig. 2 describes the various probe configurations that were considered and the one finally selected.

PASSIVE INTERMODULATION (PIM) CONSIDERATIONS

It has been the experience of UHF spacecraft suppliers and those involved in military projects dealing with ground/ship based high power transmitters that intermodulation products are generated by passive components that involve some kind of contact, be it metal-to-metal or involving plastics like kovar or graphite fiber. Systems involving high gains (>120 dB) as in the UHF transponders, or the high isolation requirements of other ground based transmitters / receivers, are especially prone to this phenomenon. The level of any IM produced by the transmit portion in the receive band has to be at least 20 dB below the power of the received signal. This condition results in a carrier to passive IM requirements (C/I) of anywhere from 140 to 200 dB depending upon the system gain, frequency plan, transmit/receive configurations and the requirements of other stations in the overall system. Table 1 describes the state-of-the-art for low PIM components. For the MUSAT program, the frequency plan currently envisaged requires only the 19th order PIM product to be less than -150 dBm with two 50 watt carriers in the transmit band.

Based upon the PIM requirements, review of the available literature [5-8] on PIM (it is meagre) and experimentation with elementary units, following steps were incorporated in the design of the duplexer:

(a) Use of aluminum for fabricating the unit.

(b) Minimization or possible elimination of tuning screws.

(c) Rectangular fingers for digits to facilitate machining out of a single block of aluminum thus minimizing contact areas.

(d) Careful selection of input/output connectors (5).

(e) Complete elimination of any and all ferrous materials like invar, Ni, steel, etc., from the duplexer configuration.

(f) General 'magnetic sanitation'.

Testing of PIM levels of -150 dBm or less represents an elaborate and expensive piece of equipment. Such a facility was provided by the Communications Research Centre (CRC), Ottawa.

Table 1

STATE-OF-THE-ART
INTERMODULATION IN PASSIVE COMPONENTS

Component	Passive IM - dBm 3rd Order Level for 2, +45 dBm Carriers	
	Conventional Units	State-of-the-Art Units
Diplexer	-70 dBm	-135 dBm
Multiplexer	-60 dBm	-120 dBm
Hybrid	-60 dBm	-140 dBm
Circulators	-70 dBm	-115 dBm
Coax Connectors	-60 to -100 dBm	-155 dBm

N.B.: Intermod Products in passive components do not follow the normal relationships with respect to changes in fundamental power or the order of the products.

PROTOTYPE MODEL AND EXPERIMENTAL RESULTS

The basic prototype unit was designed making use of the existing literature [9] on inter-digital filters. A number of design modifications were performed on the transmit filter to eliminate all tuning screws for optimum power handling capability as well as to minimize PIM. Filters are 8 and 7-pole Chebyshev designs for the transmit and receive channels respectively.

A short-circuited coaxial manifold design was chosen for combining the two filters. To achieve a compact and lower weight configuration, the receive filter is placed on top of the transmit filter with a common wall. This results in a curved manifold design to achieve the optimum distance between the coupling probes with respect to the short-circuited end of the manifold. Fig. 3 shows the photograph of the final unit. Figs. 4 to 6 describe the measured results. The achieved unloaded Q is 2,000. Measured PIM is less than -150 dBm which is close to the limit of measurement. Unit showed no breakdown for power levels of up to 200 watts in vacuum.

CONCLUSIONS

Tests carried out on the final prototype unit indicate that a duplexer with 2.0 inch ground plane spacing is capable of:

Handling 200 watts of CW power in vacuum.

19th order PIM levels of less than -150 dBm with two 50 watt carriers in the transmit band.

Achieving unloaded Qs in the range of 2,200.

This measured data establishes the UHF duplexer as a candidate design for the multi-purpose UHF satellite (MUSAT) currently under consideration by the Government of Canada.

ACKNOWLEDGEMENTS

This program was supported by the DSS Contract 101 PC-36100-6-0451, Government of Canada. Authors are indebted to many of their colleagues at CRC, Canada and Com Dev, Montreal for their helpful suggestions during the course of this program. Our very special thanks to R. Hahn of CRC for making the elaborate PIM measurements.

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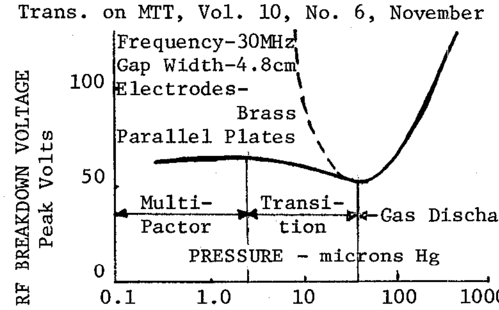

Fig. 1a Variation of RF Breakdown Voltage with Pressure (Ref. 2)

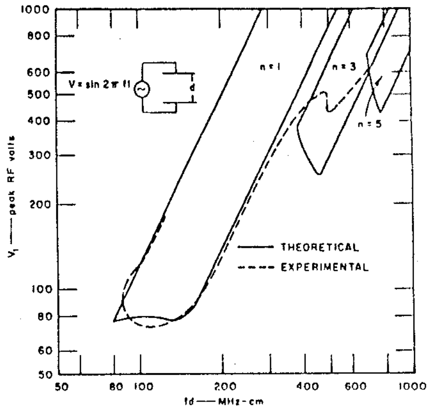

Fig. 1b Multipactor Breakdown Voltage as a Function of Frequency and Gap Width for Parallel-Plane Electrodes (Ref. 2)

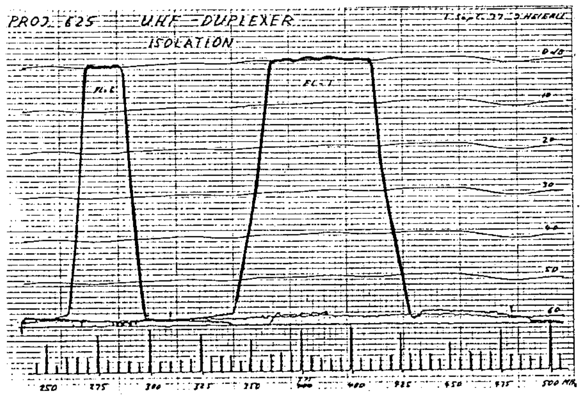

Fig. 4 Measured Isolation Response of the Prototype Duplexer

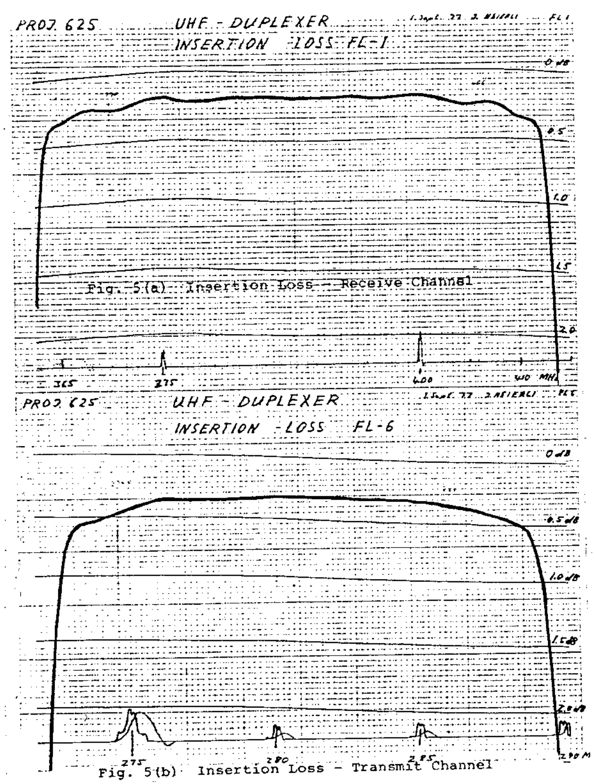

Fig. 5 Measured Insertion Loss Response of the Prototype Duplexer

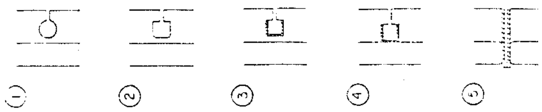

Fig. 2 Alternative Probe Configurations for the Duplexer

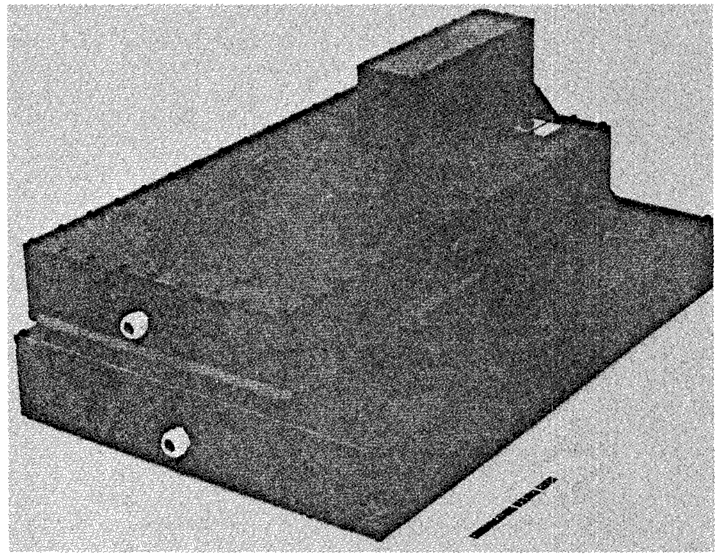

Fig. 3 Photograph of the Prototype Unit

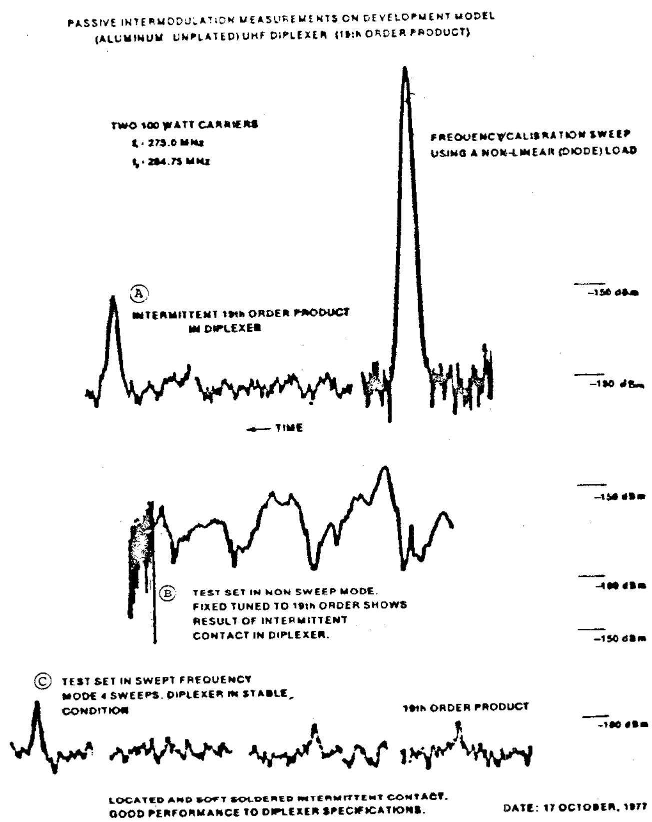

Fig. 6 Measured Passive Intermodulation on the Prototype Duplexer