COM DEV LTD.

MSAT DUPLEXER
FINAL REPORT

PROJECT NO.: 2501
FILE NO.: 01SM.36001-5-3548

- MICROWAVE PRODUCTS
- CONSULTING SERVICES

TK
5104.2
M8
M7334
1986

IC

155 SHELDON DRIVE, CAMBRIDGE, ONTARIO, CANADA N1R 7H6 • TEL.: (519) 622-2300 • TWX: 610-366-3164

TK
5104.2
M8
M733
1986

DD 10671132
DL 10/17/09

REVISION RECORD

LTR	ECN NUMBER	APPD	DATE

Industry Canada
Library - Queen
AOUT AUG 2 0 2012
Industrie Canada
Bibliothèque - Queen

COMMUNICATIONS CANADA
C R C
AOU AUG 7 1991
LIBRARY – BIBLIOTHÈQUE

WRITTEN
DATE Mario List 11 July 86

CHECKED
DATE Robert Long 11 July 86

APPROVED
DATE Tom Wai Cheung 11 July 86

COM DEV
155 Sheldon Drive
Cambridge, Ontario
Canada N1R 7H6

MSAT DUPLEXER
FINAL REPORT

DOCUMENT No.	REV.	PROJECT #2501 DSS
RPT/MST/2501/001	—	SHEET 1 OF 53

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

FORM 360/86

TABLE OF CONTENTS

ITEM	DESCRIPTION	PAGE
1.0	EXECUTIVE SUMMARY	5
2.0	INTRODUCTION	6
3.0	SUMMARY OF TASKS COMPLETED	9
4.0	DUPLEXER DESIGN ASPECTS	12
4.1	Design Trade-Off Study	12
4.2	Design Description	17
4.3	Power Handling Considerations	20
	4.3.1 Passive Inter-Modulation	20
	4.3.2 Multipaction	20
4.4	Ambient Performance Measurements	22
5.0	HIGH POWER TESTING	25
5.1	Multipaction Testing	25
5.2	PIM Testing	32
	5.2.1 Test System	32
	5.2.2 Test Results	33
6.0	RECOMMENDATIONS FOR FLIGHT UNIT	34
6.1	UHF Duplexer	34
6.2	L-Band Equipment	35
APPENDIX A	Measured Data	39

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

LIST OF FIGURES

ITEM	DESCRIPTION	PAGE
FIGURE 4.1	Computed Isolation and Return Loss Performance for Transmit Filter	18
FIGURE 4.2	Receive Filter Computed Isolation and Return Loss Performance	19
FIGURE 5.1	Multipaction Test Set-Up	28
FIGURE 5.2	Noise Floor Before Multipaction	29
FIGURE 5.3	Noise Floor During Multipaction	29
FIGURE 5.4	Multipaction Test Set-Up Using a Short Circuit	30
FIGURE 5.5	Noise Floor Rise Due to Multipaction of Duplexer	31

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

LIST OF TABLES

ITEM	DESCRIPTION	PAGE
TABLE 3.1	COM DEV Proposed Duplexer Specification	11
TABLE 4.1	Transmit Filter Electrical Performance Trade-Off	15
TABLE 4.2	Receive Filter Electrical Performance Trade-Off	16
TABLE 4.3	Measured Performance of Engineering Model	23
TABLE 4.4	Breadboard Transmit and Receive Filters Measured Performance Summary	24
TABLE 5.1	Multipaction Test Results	27
TABLE 6.1	Comparison of Transfer Function vs. Computed Insertion Loss and Mass	36
TABLE 6.2	Proposed Specifications for UHF Duplexer and Single Transmit and Receive Filters	37
TABLE 6.3	UHF Receive Filter Performance Employing Dual Mode Dielectric Resonator Filters	38

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

1.0 EXECUTIVE SUMMARY

This report describes the design data and test results for a UHF Duplexer suitable for application as a transmit/receive duplexer aboard the proposed MSAT spacecraft.

The measured results on the prototype model included in this report demonstrate that the unit meets the stringent Passive Inter Modulation (PIM), stopband rejection and multipaction requirements while at the same time exhibiting extremely low RF loss, less than half the value specified.

In the last section of the report, recommendations are made for flight specifications for the UHF duplexer on separate transmit and receive filters, as well as the implications of adoption of the L-Band frequency assignment.

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

2.0 INTRODUCTION

This work was conducted under DSS Contract No. 01SM.36001-5-3548 between August 1985 and June 1986.

The evolution of communications satellites has inevitably led to requirements for ever increasing numbers of satellite channels with smaller bandwidth and channel separations and higher channel power levels. Preserving system performance under these constraints has required great improvements in filter and multiplexer technology.

In recent years COM DEV has promoted a number of innovations leading to vast improvements in satellite filter and multiplexer performance in the UHF to EHF frequency bands. These improvements include:

a) The practical realization of waveguide manifold-coupled contiguous band multiplexers resulting in approximately a 1 dB improvement in EIRP for multi-channel satellites.

b) The use of higher order resonant modes resulting in a 30% improvement in multiplexer loss for most systems.

c) Extensive research and testing at high RF power levels from 200 MHz to 20 GHz in advancing the state-of-the-art in PIM and multipactor prevention design capability.

d) Multipath system analysis for optimization of on-board satellite filter networks to produce best possible ground-received channel characteristics for all operating conditions.

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

e) The use of asymmetric and general filter characteristics to exactly fit system specification requirements and thereby produce "lowest loss" performance.

With the incorporation of these improvements COM DEV has assumed the position of the free world's leading supplier of microwave filter and multiplexing systems for commercial satellites.

The MSAT satellite system embraces some of the fundamental advantages of communication satellites:

a) Easy access to new users.
b) Users can be mobile.
c) Large coverage area is provided immediately at start-up.

Meeting the program objectives of low cost ground transceivers and access to a large number of users, these put a number of constraints on the design of the satellite itself, since all spacecraft systems are almost always power and weight limited.

Each communication system will require filtering of the transmitted and received signals to reject all unwanted frequency signals to acceptable levels. For systems which make use of the same antenna for transmit and receive functions, a duplexer is required to perform this filtering and to properly separate the signals. If separate transmit and receive antennas are employed, then separate transmit and receive filters will be required. The purpose of this development contract was to develop a state-of-the-art transmit/receive duplexer, and to evaluate its electrical limitations and performance.

The critical design requirements are as follows:

1) Minimum RF Loss: Duplexer loss has a direct impact on satellite EIRP and receiver performance.

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

2) High Stopband Rejection: Providing high rejection of the transmitted signal (>120 dB) at the receive port prevents saturation of the receiver by the transmitted signal.

3) High Power Handling: The transmit filter is required to operate without multipaction at an RF power level of 520 Watts peak at 868 MHz.

4) Ultra-Low Passive Intermodulation (PIM) Generation: PIM products generated in the receive band by the various carriers in the transmit band must be less than -186 dBW/3 kHz in order to avoid distortion of the received signal.

5) Size and Mass: Due to spacecraft constraints the size and mass of the assembly should be minimized where this will not cause severe degradation in the four performance areas listed above.

Since items (3) and (4) above represented advances beyond the present state-of-the-art in UHF duplexer design, COM DEV constructed, as part of this contract, a high power multipaction and PIM test system to verify duplexer performance.

By incorporating the design and manufacturing capabilities developed on previous satellite contracts, COM DEV was able, in the 10 month duration of this contract, to build a duplexer which met or exceeded all of the specification requirements and thus prove the viability of this approach.

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

3.0 SUMMARY OF TASKS COMPLETED

The tasks required by the MSAT project was to build a UHF duplexer which would address the MSAT requirement using state-of-the-art design and construction.

Design Considerations were:

a) High power handling under multi-carrier operation (520 Watts peak);

b) High Tx/Rx isolation (up to 120 dB required);

c) Requirements for many units per satellite (up to 30 on some systems);

As a result, the design tasks undertaken were:

1) Trade-off study of several filter functions.

2) Design, manufacture and tune a breadboard model.

3) Design and manufacture an engineering model that incorporates: a) PIM suppression techniques and b) design the high-field areas of the duplexer to avoid destructive multipaction effects.

4) Tune the EM unit to meet or exceed the SPAR mini-spec and the COM DEV proposed spec, shown in Table 3.1.

5) Design and produce a high power multipaction and PIM test system.

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

6) Test the EM duplexer unit for PIM and multipaction performance.

All of the tasks listed above were completed.

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

TRANSMIT FILTER

PARAMETER	SPAR MINI-SPEC	COM DEV PROPOSED SPEC
Insertion Loss, dB	0.6	0.55
Passband Ripple	0.1 dB p-p over 1.33 MHz	0.1
	0.2 dB p-p over passband	0.2
Passband Frequencies, MHz	866-870	-
PIM	<-186 dBW/3 kHz	<-186 dBW/3 kHz
Rejection at Rx Band, dB	>90	>90
Power Handling in Passband, Watts pk	520	520

RECEIVE FILTER

PARAMETER	SPAR MINI-SPEC	COM DEV PROPOSED SPEC
Insertion Loss, dB	0.8	0.7
Passband Ripple	0.1 dB p-p over 1.33 MHz	0.1
	0.2 dB p-p over passband	0.2
Rejection at Rx Band, dB	>120	>120

OVERALL UNIT

PARAMETER	SPAR MINI-SPEC	COM DEV PROPOSED SPEC
Dimensions (mm)	450 x 65 x 45	400 x 120 x 160
Mass (kg)	1.2	0.9

TABLE 3.1: COM DEV Proposed Duplexer Specification

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

FORM 361/86

4.0 DUPLEXER DESIGN ASPECTS

4.1 Design Trade-Off Study

Based on the criteria discussed in Section 3.0, a design trade-off study was conducted. The study considered several different structures and electrical transfer functions. In addition, consideration was given to the design methods to address the PIM and multipaction requirements. These high power design aspects are addressed in Section 4.3.1.

The different structures considered were:

a) High ε_r dielectric loaded cavity structure;

b) TEM re-entrant cavities;

c) TEM inter-digital structure;

d) Higher Q waveguide cavity structure.

Substrate structures were not considered due to their inherently low Q and thermal dissipation problems under high power handling applications.

The highest Q ($\cong$15,000) could be obtained by the waveguide cavity structure, however, this structure is extremely large and heavy at these frequencies and was thus rejected.

Loading this structure with a high-ε_r dielectric would significantly reduce the size and weight of this structure. In recent years, temperature stable ceramics have been produced which have high microwave Q's (>10,000). These ceramics are now being employed in on-board satellite microwave filters. This structure was evaluated in the present trade-off study.

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

The second structure (TEM interdigital) has the lowest Q of the structures considered.

COM DEV's experience with this structure indicates that the maximum Q obtainable is about 2,000. In this application, this would result in higher loss and thermal dissipation than the previous structures. The inter-digital realization does have the advantages, however, of being the smallest and lightest structure.

The last structure considered was the TEM re-entrant cavity. This well-proven coaxial filter consists of quarter-wave resonators coupled by means of apertures in adjacent cavity walls. This structure is able to realize Q's of up to 7,000 at these frequencies, depending upon the size constraint chosen. Although the structure is generally larger and heavier than the inter-digital structures, the mass difference can be largely removed through the use of thin-wall aluminum construction techniques. This structure was also considered in the subsequent design trade-off study.

Two basic types of bandpass filter transfer functions were examined in the electrical trade-off study. The first was the Chebyshev function which is the simplest to realize and produces monotonically increasing stopband rejection. The second type was various orders of quasi-elliptic filter functions. In these filters, one or more transmission zeros are produced at finite frequencies. The presence of transmission zeros enhances the rejection close to the filter passband at the expense of rejection in the far stopband as compared to the Chebyshev response.

The results of the trade-off study are shown in Tables 4.1 and 4.2 for the transmit and receive filter sections, respectively.

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

As can be seen from Table 4.1, the Chebyshev transfer functions have superior insertion loss characteristics when compared to the quasi-elliptic functions. This is due to the fact that quasi-elliptic filter functions are not particularly suited to high rejection levels (>60 dB) and require a narrower bandwidth to meet such requirements. Among the Chebyshev filters, the 8-pole and 7-pole filters both exhibit acceptable insertion loss performance therefore, the 7-pole structure would be the preferred design due to its lower size and weight performance. A Q value of 6,000 was assumed for all filter simulations, this is based on realizable efficiency of 60% for silver plated cavities at this frequency.

In Table 4.2, both coaxial re-entrant cavities and dielectric loaded resonator cavities filters are compared. Once again, a Q of 6,000 is assumed for the coaxial re-entrant structure whereas a Q of 10,000 is assumed for the dielectric resonator structure. The Q value assumed for the dielectric resonator filter is fairly conservative since COM DEV has realized Q's in excess of 8,000 at 4 GHz using dielectric resonators. In addition, the dielectric resonator is realized in a dual-mode structure, i.e., each physical resonator is excited in two orthogonal modes. This implies that only half the number of physical cavities are required for the dielectric resonator solution than for the re-entrant coaxial filters. As can be seen, the dielectric resonator filter structures possess significantly lower insertion loss and volume than the re-entrant coaxial cavities. Despite this, the dielectric resonator filter is about 20% heavier for the same order of filter due to the high mass of the dielectric material. Due to the higher mass prediction, potential problems in heat dissipation under high power conditions and the six-months' lead time required to procure this material, this design approach will not be pursued in this study. However, if the receive path loss becomes a dominant issue, we recommend the use of dielectric load receive filter should be considered as a potential candidate.

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

TRANSFER FUNCTION	COMPUTED INSERTION LOSS (dB)	COMPUTED REJECTION AT 821-825 MHz (dB)	COMPUTED MASS (g) (SINGLE FILTER)	COMPUTED DIMENSIONS (in.) (SINGLE FILTER)
5-Pole Chebychev (BW = 10 MHz)	0.44	90	420	15 x 2.85 x 3.75
6-Pole Chebychev (BW = 16 MHz)	0.39	90	500	17.5 x 2.85 x 3.75
7-Pole Chebychev (BW = 23 MHz)	0.30	90	610	20 x 2.85 x 3.75
8-Pole Chebychev (BW = 30 MHz)	0.29	90	700	22.5 x 2.85 x 3.75
6-Pole Quasi-Elliptic With Asymmetric Stopband (BW = 12 MHz)	0.49	90	500	17.5 x 2.85 x 3.75
7-Pole Quasi-Elliptic With Asymmetric Stopband (BW = 18 MHz)	0.46	90	500	17.5 x 2.85 x 3.75
8-Pole Quasi-Elliptic With Asymmetric Stopband (BW = 27 MHz)	0.39	90	600	20 x 2.85 x 3.75
PROPOSED SPAR SPEC:	0.6	90	-	-

NOTE: Filter Q = 6,000
Filter structure TEM re-entrant coaxial cavities

TABLE 4.1: Transmit Filter Electrical Performance Trade-Off

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

FORM 361/86

TRANSFER FUNCTION AND STRUCTURE	COMPUTED PASSBAND INSERTION LOSS (dB)	COMPUTED REJECTION AT 866-870 MHz (dB)	COMPUTED MASS (g) (SINGLE FILTER)	COMPUTED DIMENSIONS (in.) (SINGLE FILTER)
6-Pole Chebychev (TEM) (BW = 9.5 MHz)	0.55	120	500	17.5 x 2.85 x 3.75
7-Pole Chebychev (TEM) (BW = 14 MHz)	0.44	120	610	20 x 2.85 x 3.75
8-Pole Chebychev (TEM) (BW = 19 MHz)	0.40	120	700	22.5 x 2.85 x 3.75
9-Pole Chebychev (TEM) (BW = 24 MHz)	0.35	120	815	25 x 2.85 x 3.75
Dielectric Resonator 5-Pole Chebychev (BW = 5 MHz)	0.51	120	720	9.5 x 3 x 3
Dielectric Resonator 6-Pole Chebychev (BW = 9.5 MHz)	0.34	120	720	9.5 x 3 x 3
Dielectric Resonator 7-Pole Chebychev (BW = 14 MHz)	0.27	120	960	12.2 x 3 x 3
Dielectric Resonator 8-Pole Chebychev (BW = 19 MHz)	0.26	120	960	12.2 x 3 x 3
PROPOSED SPAR SPEC:	0.8	120	-	-

NOTE: TEM Filter Q = 6,000
Dielectric Resonator Filter Q = 10,000

TABLE 4.2: Receive Filter Electrical Performance Trade-Off

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

FORM 361/86

4.2 Design Description

Based on the results of the trade-off study, the duplexer was constructed using the TEM re-entrant cavities structure. The unit consists of a 7-pole receive filter and a 6-pole transmit filter. The two filters share a common wall in order to reduce the overall mass of the assembly and to facilitate common port coupling. To allow adjustments to common port coupling, a unique common port cavity was designed. The cavity consists of a removable end plate so that fine adjustments to the common port coupling could be accomplished after device integration. The remainder of the unit's construction employed cavity sections with removable irises between them to aid in the tuning process.

The cavities and irises were manufactured from aluminum and were silver plated (plating thickness 0.001").

Figures 4.1 and 4.2 present plots of the computed performances of the transmit and receive filters, respectively.

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

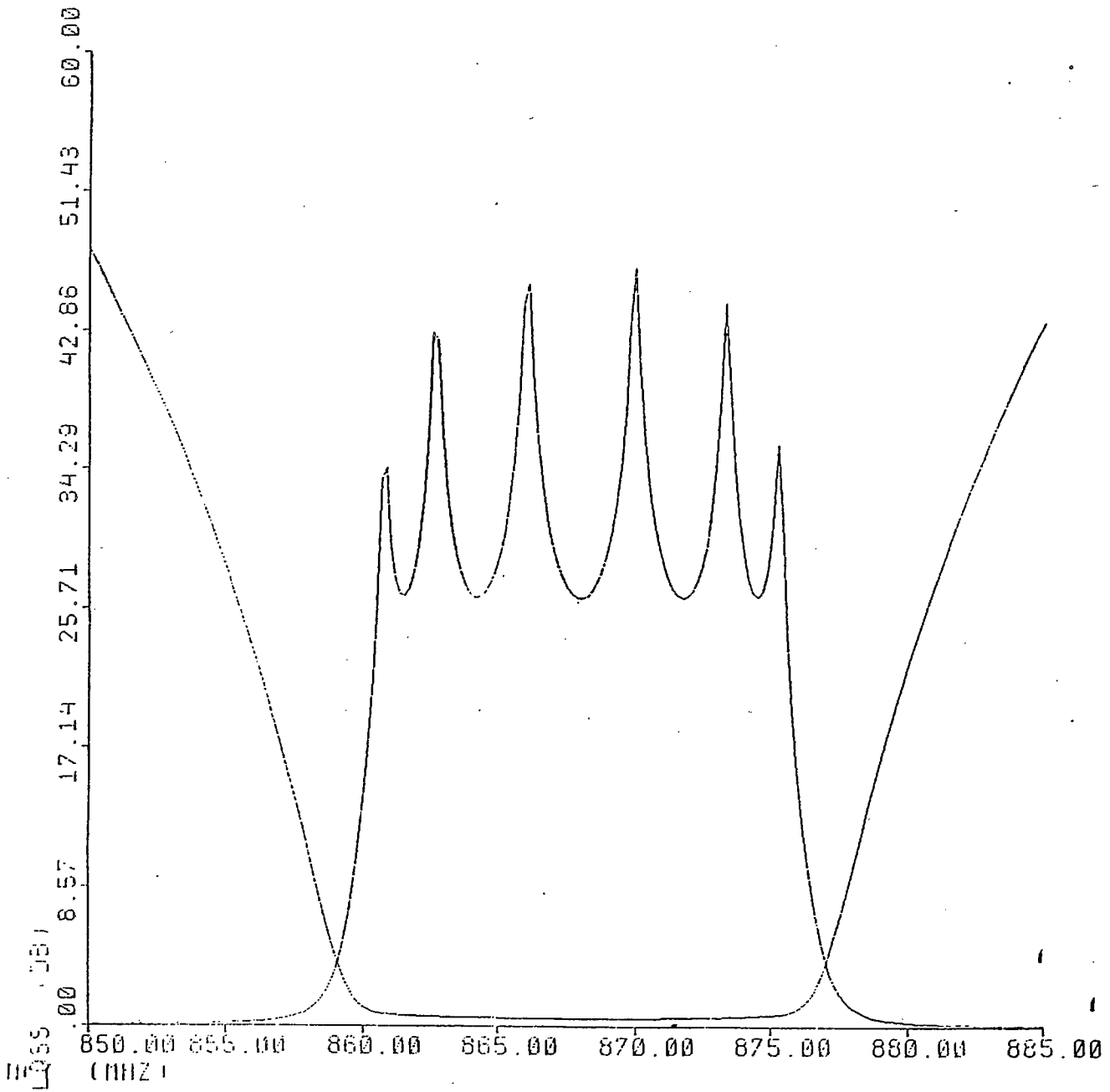


FIGURE 4.1: Computed Isolation and Return Loss Performance for Transmit Filter

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

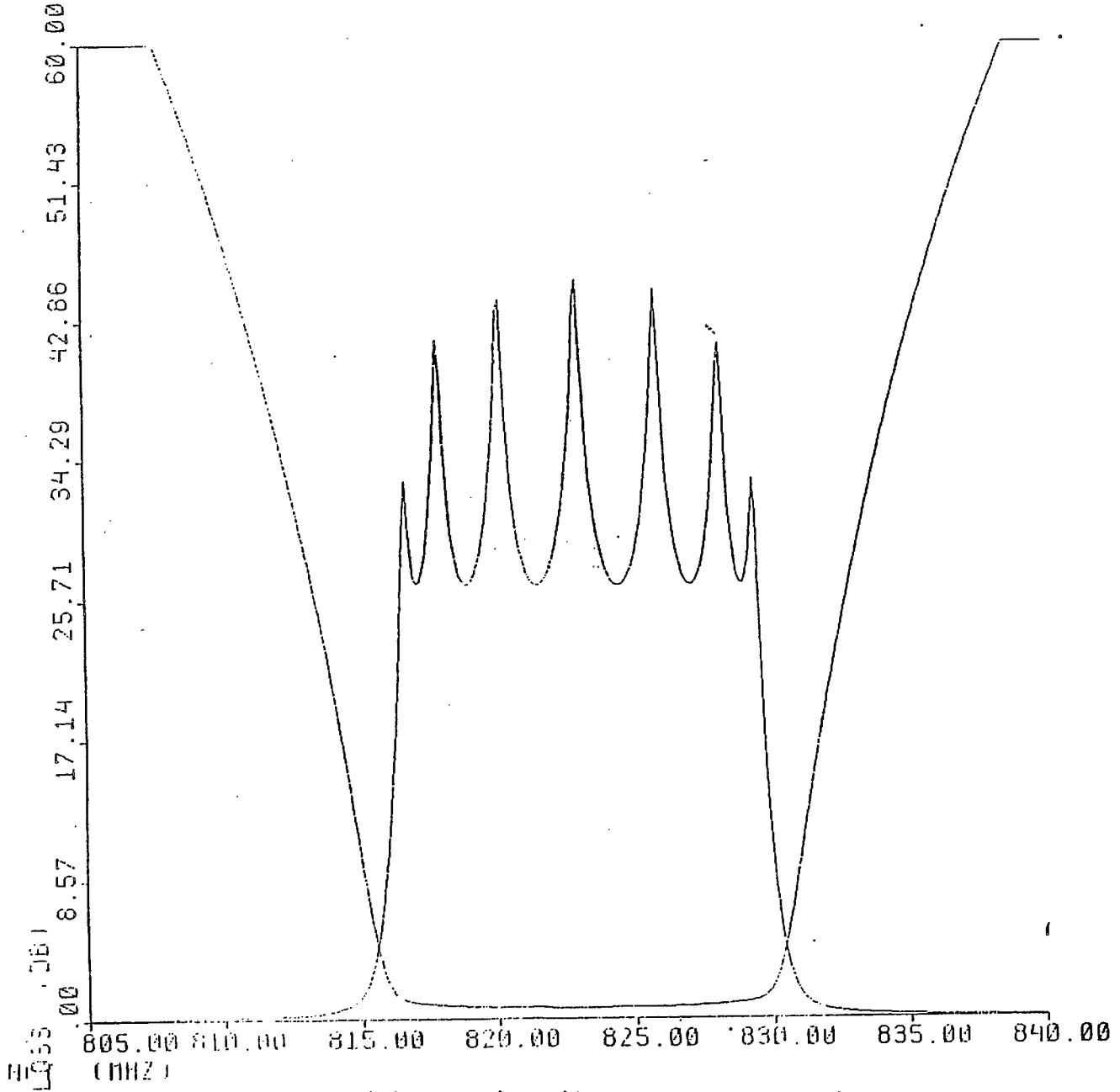


FIGURE 4.2: Receive Filter Computed Isolation and Return Loss Performance

4.3 Power Handling Considerations

4.3.1 Passive Inter-Modulation

The requirements for PIM over the 821.825 MHz receive band is to be below -186 dBW/3 kHz when the transmit band contains a 130 Watt multi-carrier signal distributed evenly over 1.33 MHz. This requirement corresponds to a transmit signal to PIM product ratio of -181 dB.

COM DEV has considerable experience in PIM reduction techniques and PIM testing for aerospace hardware.

The features which are incorporated in this design are:

1) The cavity flanges are undercut to ensure that no resistive contacts are present when the duplexer is integrated.

2) The unit is plated with 0.001" thick silver to ensure RF energy will not penetrate to the nickel sublayer. The silver plating was conducted at COM DEV's plating facility with very stringent controls on the plating process.

3) All high power ports employ TNC connectors. This connector is known to possess the properties of low PIM and high power handling capability.

The use of these techniques reduced the PIM level below the level specified by the MSAT project.

4.3.2 Multipaction

The multipaction effect is an RF resonant discharge sustained by the emission of secondary electrons from the discharging surfaces. A number of conditions have to be satisfied for the

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

multipaction to take place. The electron mean free path has to be greater than the gap dimensions, which is normally the case at pressures below 10^{-4} mbar. Secondly, the secondary electron emission coefficient of the discharging surfaces (i.e., surface work function) must be equal to or greater than unity. Since multipaction is a resonant discharge, the correct values of RF voltage, gap spacing and field frequency are necessary to ensure that each electron crosses the gap within one half cycle of the RF field or some higher integral multiple. Thus, multipaction is dependent on the frequency gap (Fd) product and the applied voltage across this gap.

In this case, assuming that:

Peak power = 520 Watts
Filter Impedance = 77 Ω

and using $V = \sqrt{2PZo}$

yields Fd = 530.1 GHz - mm

and thus d = 0.621 cm

Applying a safety margin of 2 this yields a minimum allowable gap of 1.2 cm between unprotected metal surfaces.

Under the present design this condition is met in all locations except in the vicinity of the coupling probes. At these locations one of the exposed metal surfaces will be coated with a dielectric exhibiting a high surface work function (i.e., high resistance to multipaction). The material which will be employed in the present application is teflon (PTFE). With these measures in place, the expected multipaction breakdown level is 800 Watts.

© Her Majesty the Queen In Right of Canada (1986) as represented by the Minister of Supply And Services.

4.4 Ambient Performance Measurements

Analysis of the measured performance indicates that the Q of the receive and transmit filters are 6500 and 7000, respectively. As a result, the insertion loss values were extremely good. The out-of-band rejection was measured by using a spectrum analyzer. An out-of-spec condition occurs at the receive filter rejection point of 866 MHz. The filter measures 118 dB, the spec is 120 dB. By decreasing the bandwidth to 15.6 MHz from 16.6 MHz, the isolation will increase to 121 dB. Computer simulation shows that with this change in rejection the insertion loss impact will be less than 0.01 dB.

The measured plots of the duplexer are presented in Appendix A. A performance summary is presented in Table 4.3.

Table 4.4 summarizes the measured performance of the individual transmit and receive filter sections.

As can be seen from Tables 4.3 and 4.4 extremely good correlation exists between the measured and computed performance for the duplexer assembly.

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

PARAMETER	SPECIFICATION	TRANSMIT FILTER	RECEIVE FILTER
Filter Q	---	7000	6500
Filter Bandwidth (Measured), MHz	---	15.3	16.6
Passband Insertion Loss			
At Tx	0.6	.38	---
At Rx	0.8	---	.38
Passband Ripple, dB p-p Over Any 1.33 MHz	0.1	.05	.03
Over the Band	0.2	.06	.04
Return Loss, dB	22	22.3	23.1
Rejection, dB			
At Rx	90	94	--
At Tx	120	--	118

TABLE 4.3: Measured Performance of the Duplexer Engineering Model

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

FORM 361/86

TRANSMIT FILTER

PARAMETER	SPECIFICATION	MEASURED * PERFORMANCE
Filter Q	--	6,000
Equiripple Bandwidth, MHz	--	15.2
Insertion Loss, dB	0.6	0.32
Passband Ripple, dB p-p		
Over 1.33 MHz	0.1	0.05
Over the Band	0.2	0.08
Return Loss, dB	22	21
Rejection at Rx, dB	90	>95

RECEIVE FILTER

PARAMETER	SPECIFICATION	MEASURED * PERFORMANCE
Filter Q	--	5,800
Equiripple Bandwidth, MHz	--	16.4
Insertion Loss, dB	0.8	0.39
Passband Ripple, dB p-p		
Over 1.33 MHz	0.1	0.05
Over the Band	0.2	0.08
Return Loss, dB	22	21
Rejection at Tx, dB	120	>95

* Measured Performance is for separate filters only.

TABLE 4.4: Breadboard Individual Transmit and Receive Filters Measured Performance Summary

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

5.0 HIGH POWER TESTING

5.1 Multipaction Testing

Using the test set-up shown in Figure 5.1, the duplexer was tested for multipaction. The spectrum analyzer was used to monitor the out-of-band noise floor. When multipaction occurs the noise floor around the carrier will increase by about 10 to 20 dB. In addition the input, output and reflected powers were also monitored for signs of multipaction breakdown.

The duplexer was placed in the vacuum chamber and connected as shown in Figure 5.1. The two amplifiers were phased together and the input power adjusted to 50 watts. The power was slowly increased stopping for 10 minutes at 50 watt intervals until a maximum input power of 426.6 watts was reached. No sign of multipaction was detected.

In order to verify that the test set-up could detect multipaction, a 2-pole filter which was designed to multipact at 50W was placed in the vacuum chamber and connected as shown in Figure 5.1. Again, the two amplifiers were phased together and the power was increased slowly. An increase in the noise floor and the reflected power was noticed when the input power reached approximately 55W indicating that the set-up could detect multipaction. Pictures of the noise floor before and during multipaction are shown in Figures 5.2 and 5.3.

To increase the peak power seen by the filter an adjustable short was placed at the output of the duplexer as shown in Figure 5.4. At each power level, the variable short was stepped through all phases to apply a standing wave of four times the input power level to every point within the duplexer. Again, the input voltage was increased slowly and this time multipaction was detected at a peak power of equivalent to 950W. A picture of the

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

increase in the noise floor is shown in Figure 5.5. The power levels at which the short was adjusted in order to change the position of the standing wave are given in Table 5.1.

The 2-pole filter was now connected as shown in Figure 5.4 and tested in the same manner as the duplexer. Multipaction was detected at a peak power of 47W indicating that this method gives the same results as using the set-up shown in Figure 5.2.

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

INPUT POWER (WATTS)	PEAK INPUT POWER (WATTS)	PEAK OUTPUT POWER (WATTS)	MULTIPACTION DETECTED
50	163	159	NO
100	300	296	NO
144	477	449	NO
166	551	480	NO
240	720	745	NO
288	957	916	NO
316	1027	950	YES

TABLE 5.1: Multipaction Test Results

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

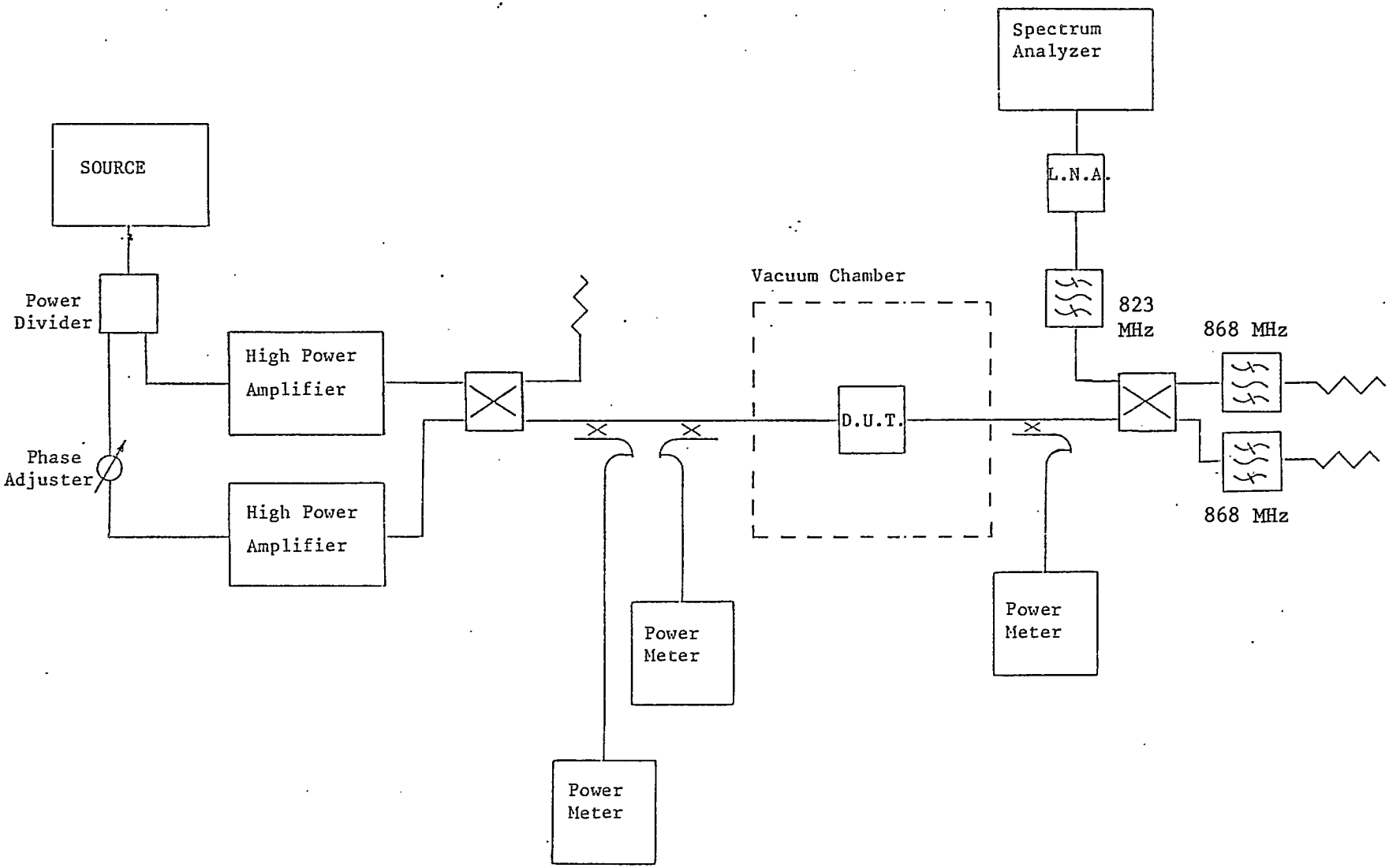


FIGURE 5.1: Multipaction Test Set-Up

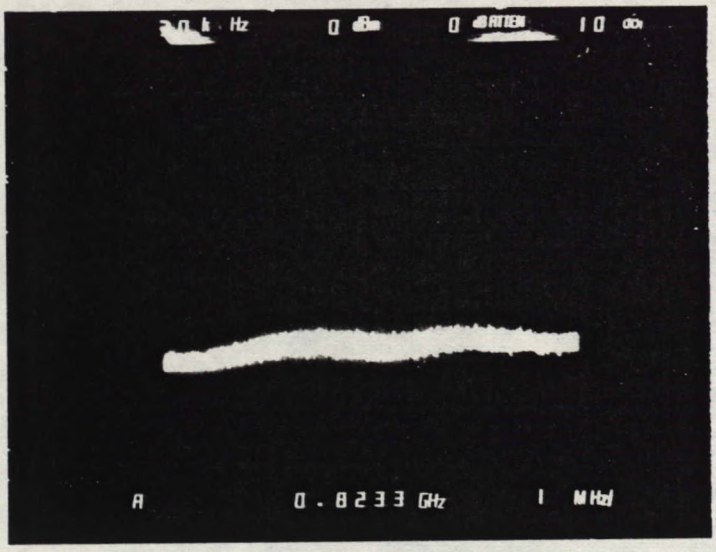


FIGURE 5.2: Noise Floor Before Multipaction

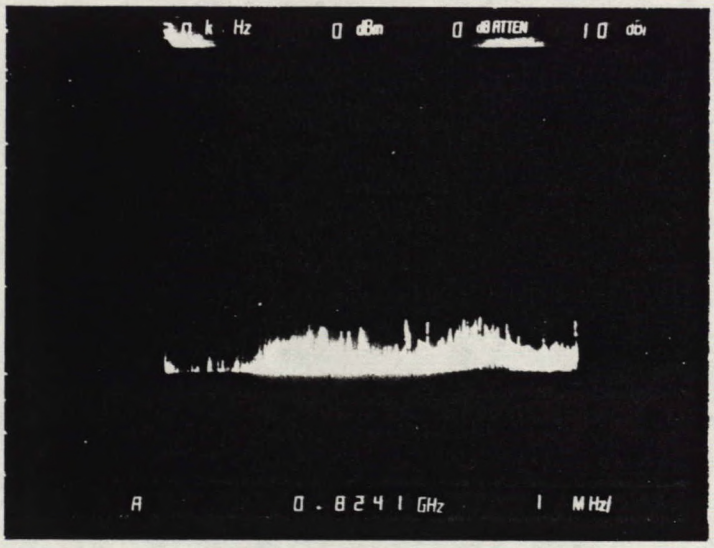


FIGURE 5.3: Noise Floor During Multipaction

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

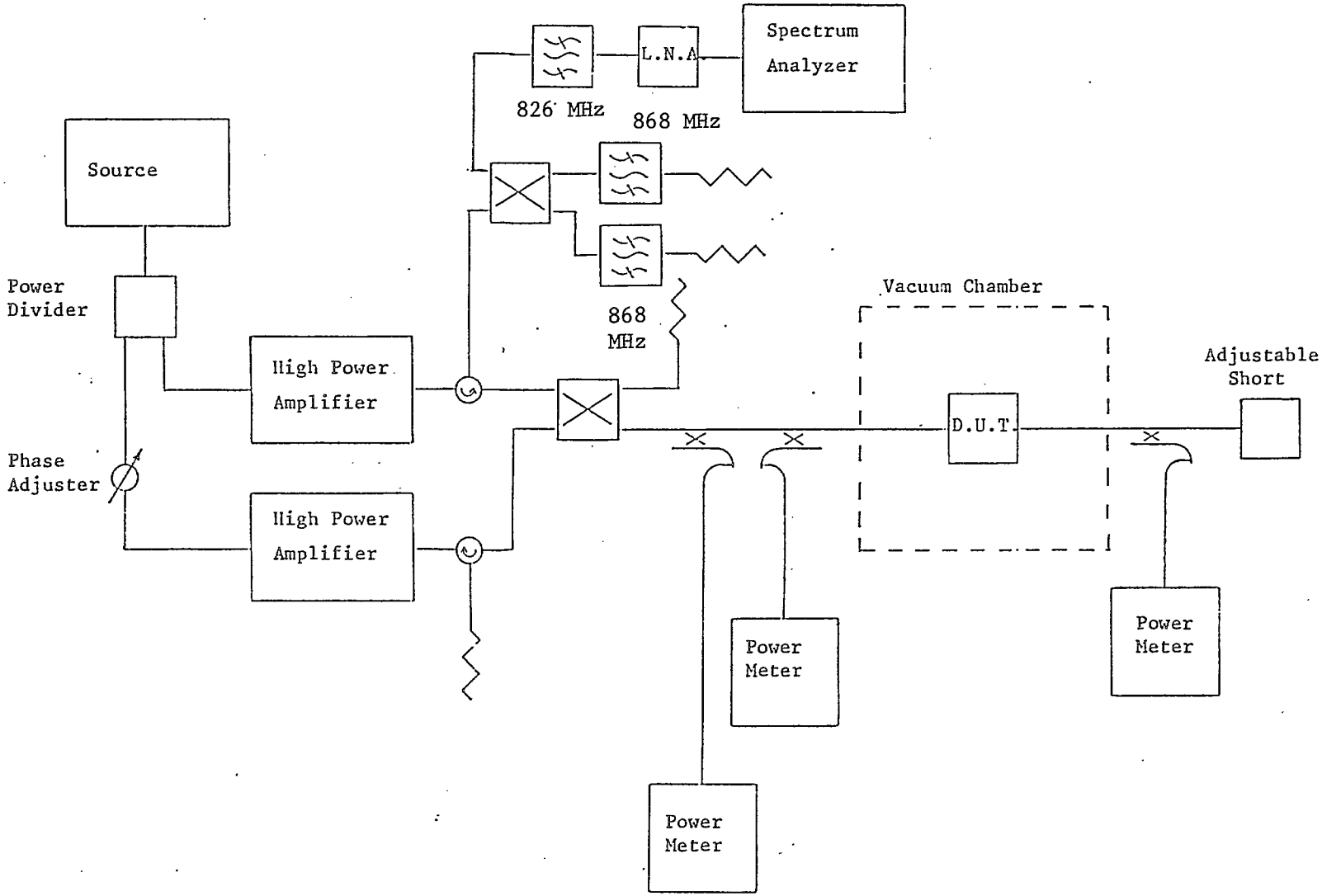


FIGURE 5.4: Multipaction Test Set-Up Using a Short Circuit

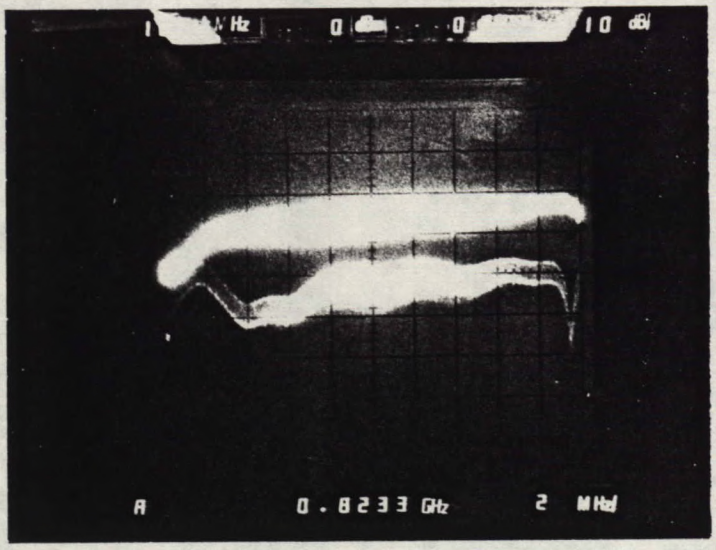


FIGURE 5.5: Noise Floor Rise Due to Multipaction of Duplexer

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

5.2 Passive Intermodulation (PIM) Testing

5.2.1 Test System

The duplexer was tested for PIM using the test set-up shown in Figure 5.6.

Initial tests showed very high levels of RF (@ -80 dBW) at the carrier frequencies and at the intermodulation frequencies. It was found that these high levels of RF were due to RF leaking from the amplifiers and connectors and then leaking back into the system just prior to the LNA's.

The intermodulation products detected were not the result of PIM since some products were at the same power levels as the carriers. The most likely sources of these intermodulation products are:

1) Due to RF leakage both carriers may be present at the input of the high power amplifiers. Non-linearities in the HPA's then result in intermodulation products which are amplified to approximately the same level as the carriers.

2) The high level of RF was saturating the LNA's causing them to go non-linear. These non-linearities would then result in intermodulation products being produced.

In order to reduce the level of RF leakage extensive RF shielding was added to the system. The effectiveness of the shielding was tested by disconnecting the input to the LNA's and powering up the amplifiers to 200 Watts. Figure 5.7 shows that the level of RF leaking into the LNA's is about -140 dBW. When the coax cable connecting the LNA's to the duplexers was added these levels increased to about -125 dBW.

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

The sensitivity of the detection system was determined by feeding a -150 dBW signal into the input of the LNA's and then decreasing the resolution bandwidth of the spectrum analyzer. It was found that reducing the resolution bandwidth below 1 kHz resulted in incorrect levels being displayed on the spectrum analyzer. The resolution bandwidth was therefore set at 1 kHz resulting in a -172 dBW noise floor.

5.2.2 Test Results

The two carriers were set at 866 and 867.33 MHz and the high power amplifiers were powered up to +23 dBW each. The receive band was then checked for the presence of the 63rd, 65th, 67th and 69th order PIM product. No PIM was detected above the -172 dBW noise floor. Typical levels measured are shown in Figures 5.7 and 5.8. The carrier spacing was then adjusted to 2 MHz and 3 MHz to test for the 43rd, 45th and 47th order PIM products and the 29th and 31st order PIM products, respectively. Again, no PIM was detected above the -172 dBW noise floor. Figures 5.9 and 5.10 show measurements with a 2 MHz carrier separation and Figures 5.11 and 5.12 show measurements with a 3 MHz carrier separation.

While COM DEV could not verify that the -186 dBW specification for PIM was met, it was verified that the 63rd order PIM product was less than -170 dBW (the limit of the test equipment). Previous experience at COM DEV has shown that in general as the order of the PIM product increases the level of the PIM product decreases. Based on this and the fact that no PIM was detected at the 29th order product COM DEV feels confident that the duplexer does meet the specification for PIM.

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

6.0 RECOMMENDATIONS FOR FLIGHT UNIT

In light of the success of this duplexer development program, several clear recommendations can be made for the MSAT flight program and for future development work. The recommendations will be given both for UHF and L-Band systems.

6.1 UHF Duplexer

Due to the extremely good correlation between computed and measured results, Tables 4.1 and 4.2 presented earlier can be used to provide trade-offs between loss, size, and mass under to condition that the rejection requirements are met. If the rejection requirements can be relaxed then, in general, lower insertion loss values and smaller size and mass are possible as shown in Table 6.1.

Based on the results of this development study, the recommended duplexer design is a 6-pole receiver filter with a 5-pole transmit filter both realized in a re-entrant coaxial cavity structure to realize a Q in excess of 6000. The proposed specifications for the duplexer and the single filters are shown in Table 6.2. This unit would comply with all existing design requirements.

If further improvements in the loss, size and mass of the receive filter are desired, then it is strongly recommended that the use of dielectric resonator ceramics be investigated for this filter. Table 6.3 outlines the performance which would be achieved based on currently available materials.

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

6.2 L-Band Equipment

If the L-Band frequencies are selected for this program, then the recommended designs would be the re-entrant coaxial structure for the transmit filter and the dual mode dielectric resonator structure for the receive filter. Insertion loss performance could only be maintained if the percentage bandwidth and rejection characteristics were not changed.

In general, by maintaining the same duplexer electrical design approach, by maintaining the power handling capability, the assembly mass would be reduced by a factor of two, the volume would be reduced by a factor of four while the insertion loss will be increased by a factor of 1.4. Thus, if the L-Band frequency plan is determined, trade-offs would need to be initiated to determine optimal filter performance characteristics.

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

RECEIVE FILTER

TRANSFER FUNCTION	BANDWIDTH (MHz)	COMPUTED INSERTION LOSS (dB)	COMPUTED REJECTION (866-870 MHz)	MASS OF SINGLE FILTER (kg)
7-Pole Chebyshev	16.6	0.38	120	0.69
6-Pole Chebyshev	16.6	0.31	91	0.54
6-Pole Chebyshev	10.5	0.49	120	0.54

Q = 6500

TRANSMIT FILTER

TRANSFER FUNCTION	BANDWIDTH (MHz)	COMPUTED INSERTION LOSS (dB)	COMPUTED REJECTION (821-825 MHz)	MASS OF SINGLE FILTER (kg)
6-Pole Chebyshev	15.2	0.38	90	0.54
5-Pole Chebyshev	15.2	0.30	77	0.40
5-Pole Chebyshev	10.0	0.44	90	0.40

Q = 7000

TABLE 6.1: Comparison of Transfer Functions vs. Computed Insertion Loss and Mass

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

ITEM	PROPOSED SPECIFICATION DUPLEXER Tx	DUPLEXER Rx	SINGLE FILTERS Tx	SINGLE FILTERS Rx
Design Description	5-Pole Chebyshev Re-Entrant Coax	6-Pole Chebyshev Re-Entrant Coax	5-Pole Chebyshev Re-Entrant Coax	6-Pole Chebyshev Re-Entrant Coax
Usable Bandwidth, MHz	4	4	4	4
Design Bandwidth, MHz	12	11	10	9.5
Passband Loss, dB	0.40	0.50	0.44	0.55
Passband Ripple, dB p-p	<0.05	<0.05	<0.06	<0.06
Rejection, dB				
At Tx Band	--	>120	--	>120
At Rx Band	>90	--	>90	--
Power Handling, W-peak	>700	--	>900	--
PIM, dBW/3 kHz				
At Rx Band	<-170	--	<-170	--
Passband Return Loss, dB	>22	>22	>22	>22
Mass, kg	0.75		0.42	0.54
Dimensions, inches				
Length	17.5		15.0	17.5
Width	5.0		3.0	3.0
Height	4.0		4.0	4.0

TABLE 6.2: Proposed Specifications for UHF Duplexer and Single Transmit and Receive Filters

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

	ESTIMATED RECEIVE FILTER PERFORMANCE	
Dielectric Constant	36	80
Resonator Q	10,000	6,000
Transfer Function	6-Pole Chebyshev	6-Pole Chebyshev
Insertion Loss, dB	0.30	0.50
Rejection at Tx Band, dB	120	120
Mass, kg	0.72	0.40
Dimensions, inches		
Length	9.5	5.0
Width	3.0	1.5
Height	3.0	1.5

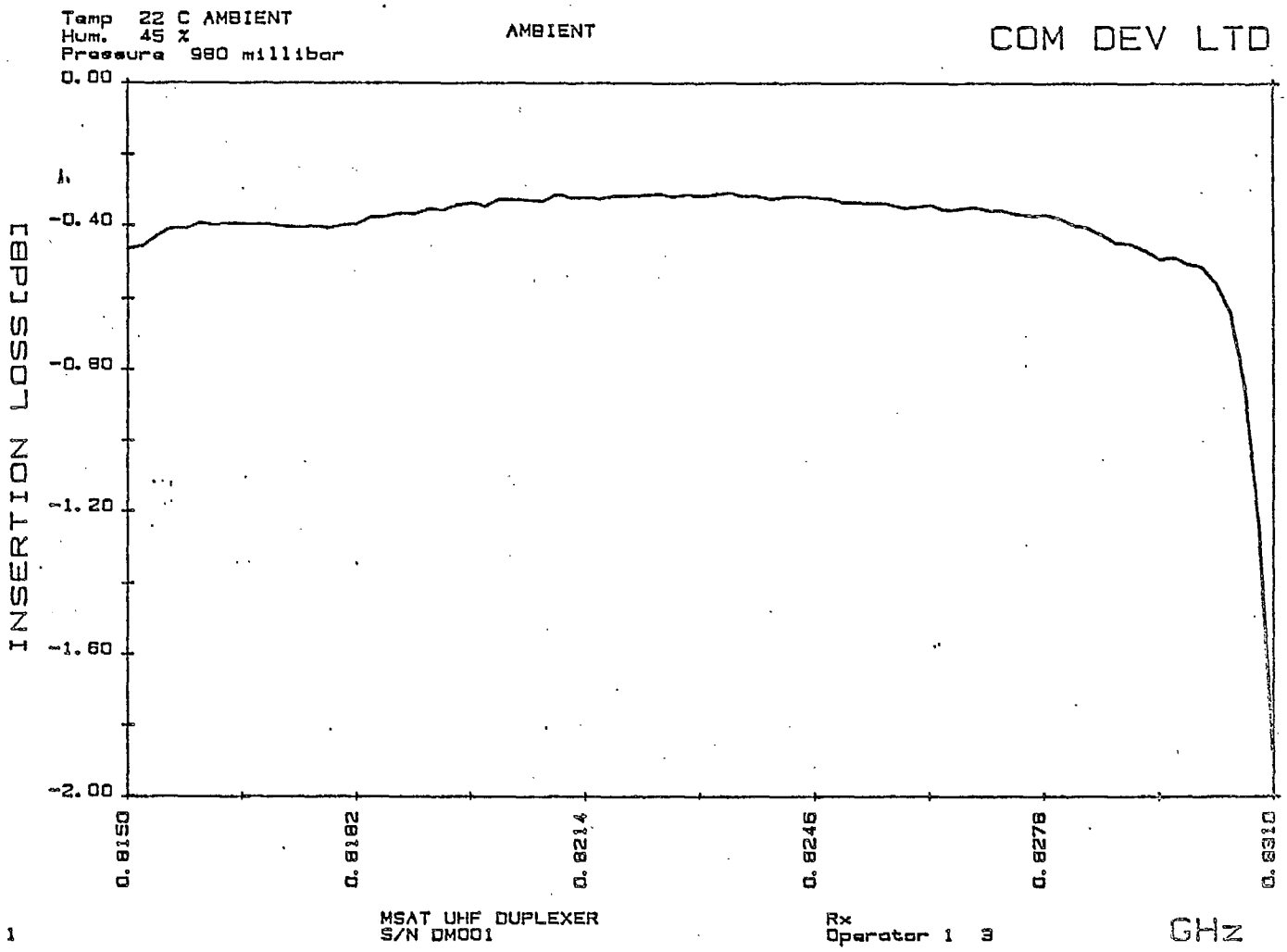
TABLE 6.3: UHF Receive Filter Performance Employing Dual Mode Dielectric Resonator Filters

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

APPENDIX A

MEASURED DATA

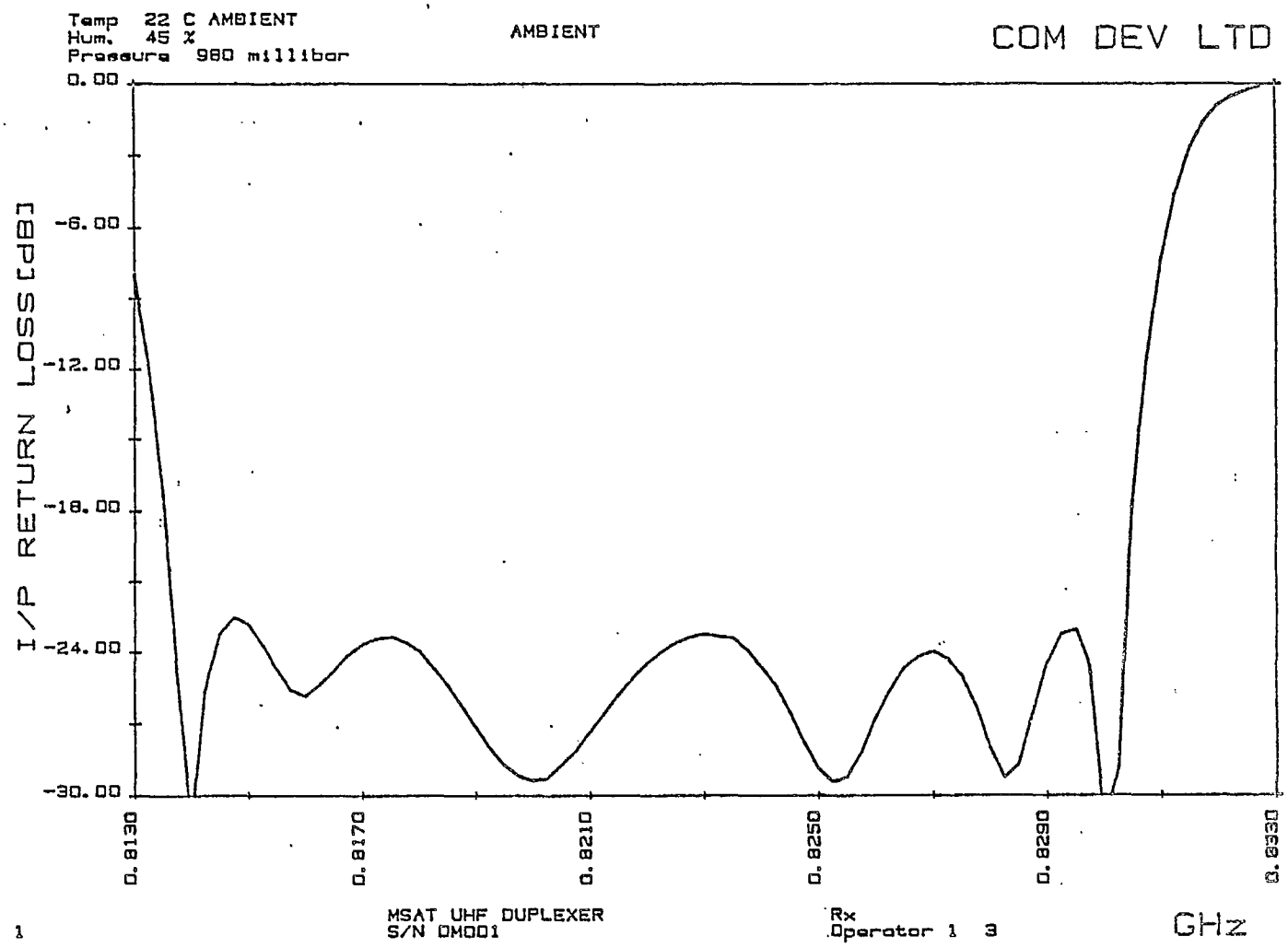
© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.



Receive Filter - Measured Insertion Loss Performance

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

DOCUMENT No.	REV.	COM DEV
RPT/MST/2501/001	—	SHEET 40

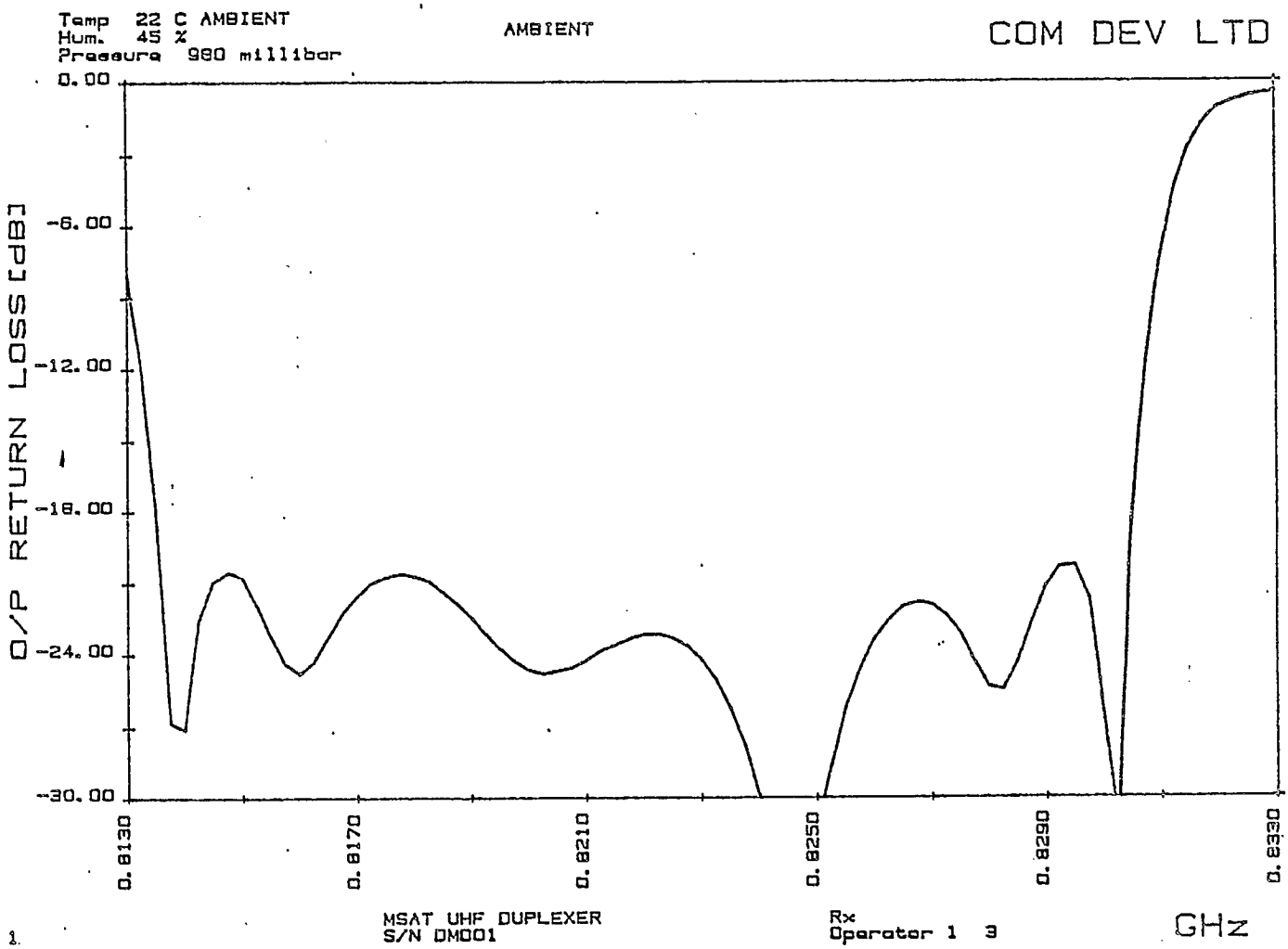


Receive Filter - Measured Input Return Loss Performance

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

DOCUMENT No.	REV.	COM DEV
RPT/MST/2501/001	—	SHEET 41

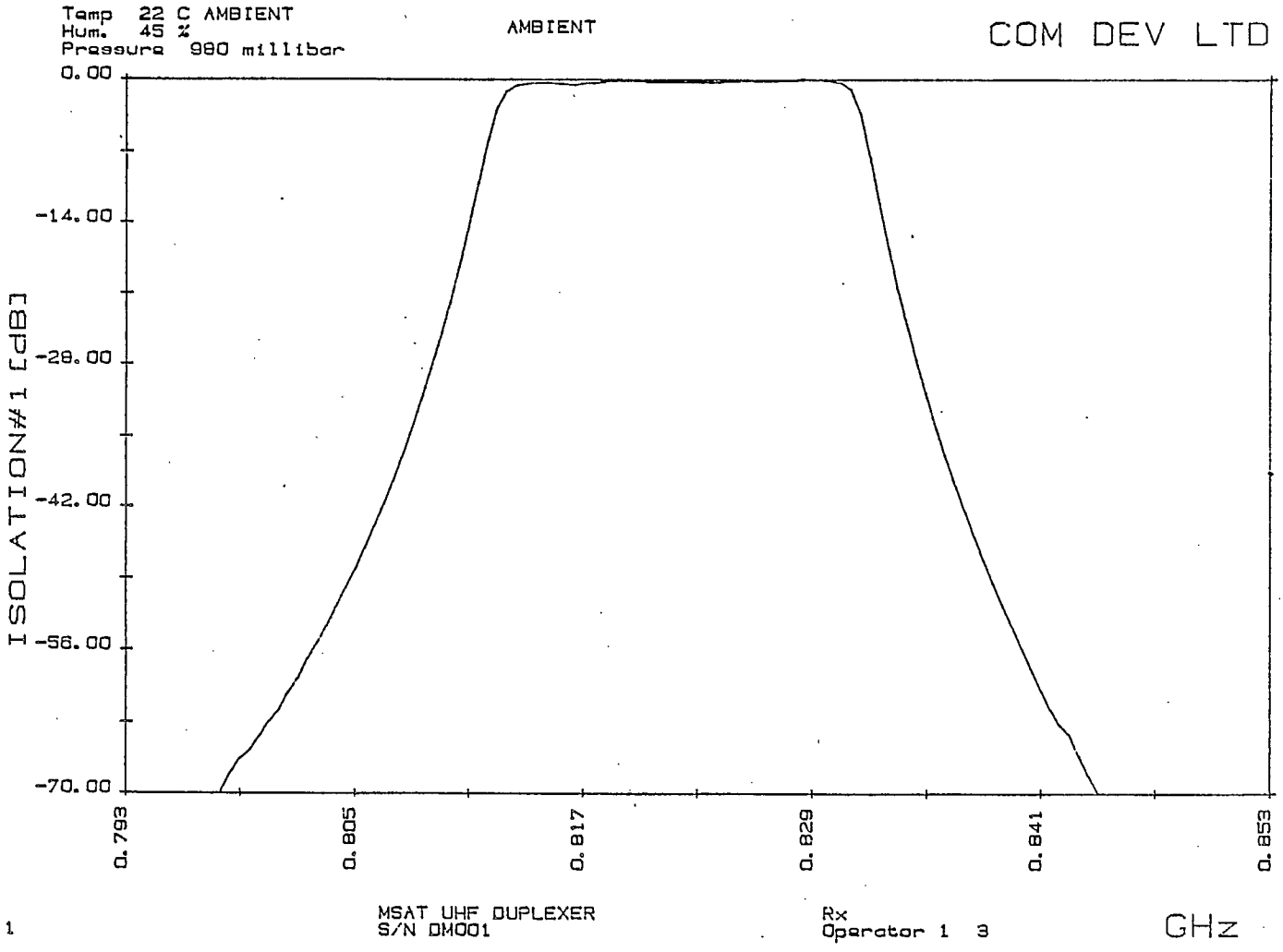
FORM 361/86



Receive Filter - Measured Output Return Loss Performance

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

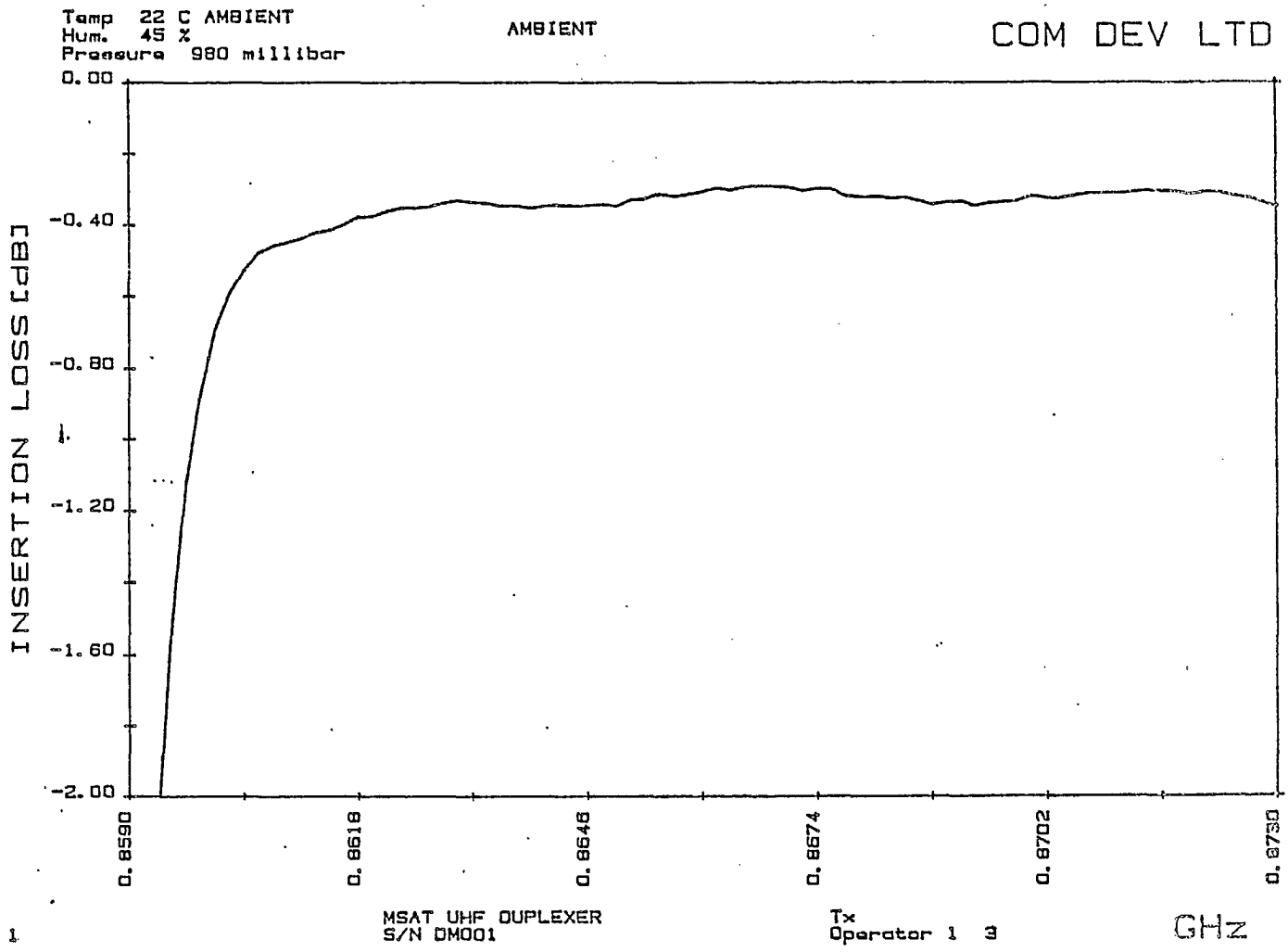
DOCUMENT No.	REV.	COM DEV
RPT/MST/2501/001	—	SHEET 42



Receive Filter - Measured Isolation Performance

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

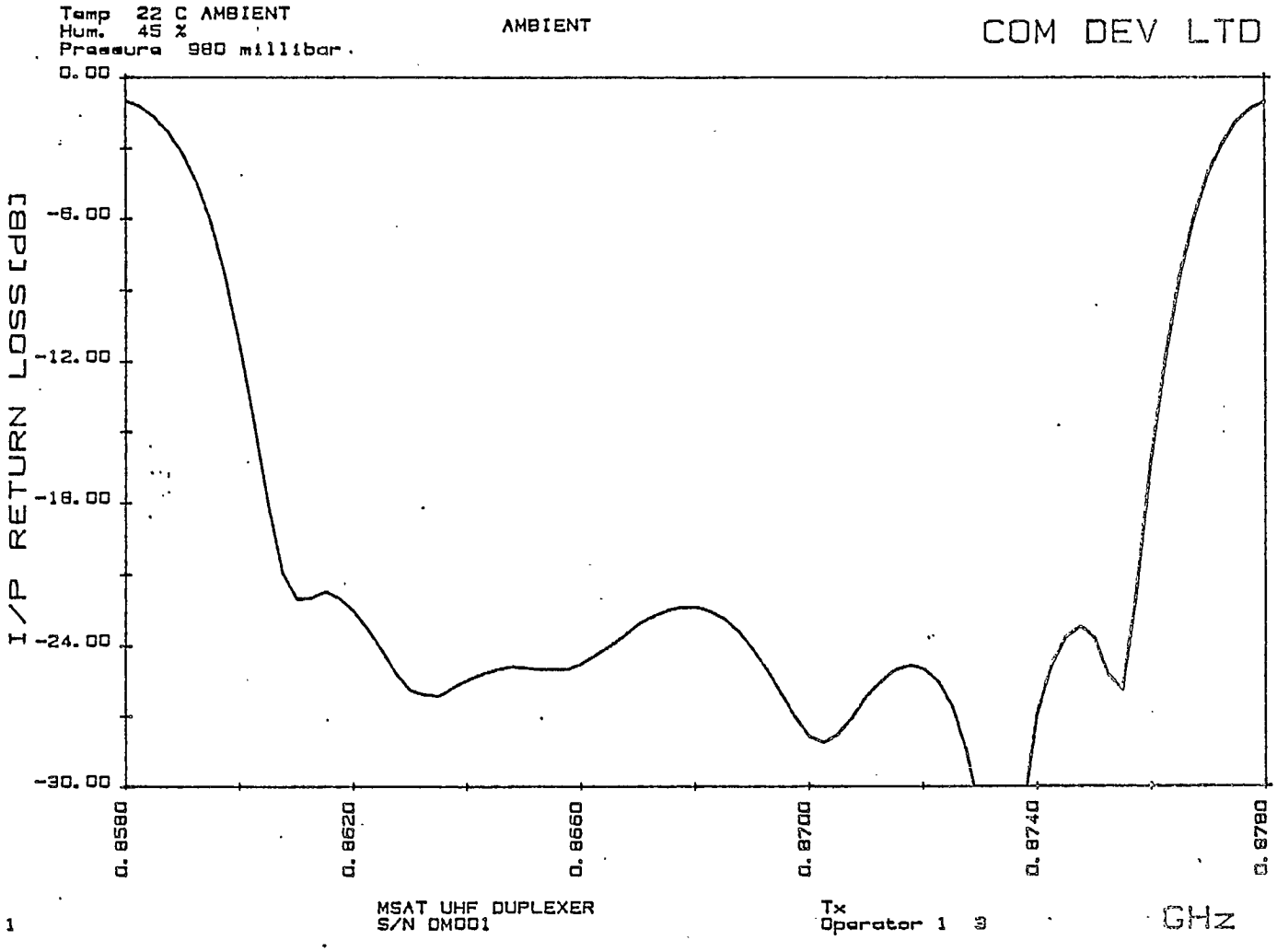
DOCUMENT No.	REV.	COM DEV
RPT/MST/2501/001	—	SHEET 43



Transmit Filter - Measured Insertion Loss Performance

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

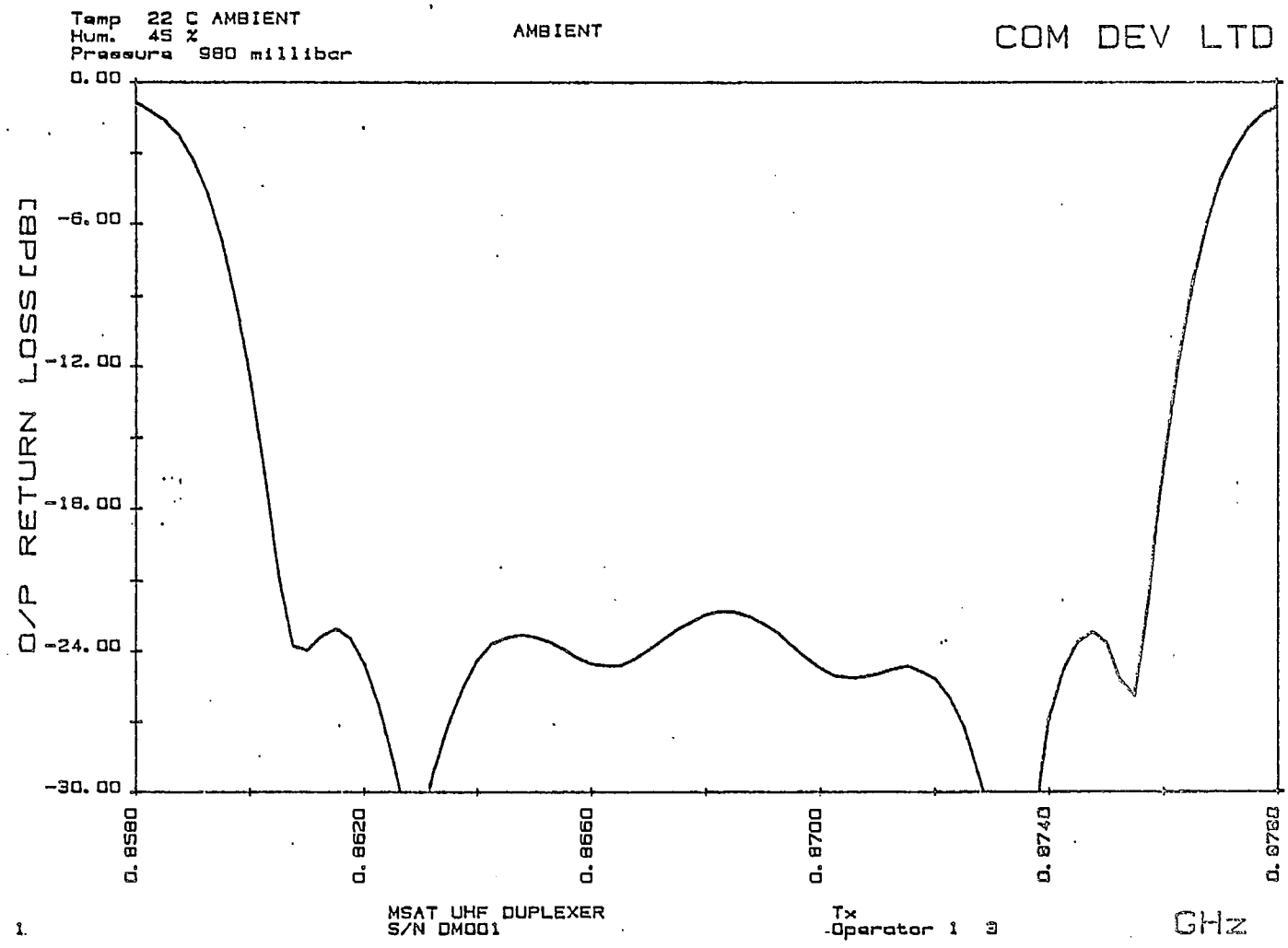
DOCUMENT No.	REV.	COM DEV
RPT/MST/2501/001	——	SHEET 44



Transmit Filter - Measured Input Return Loss Performance

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

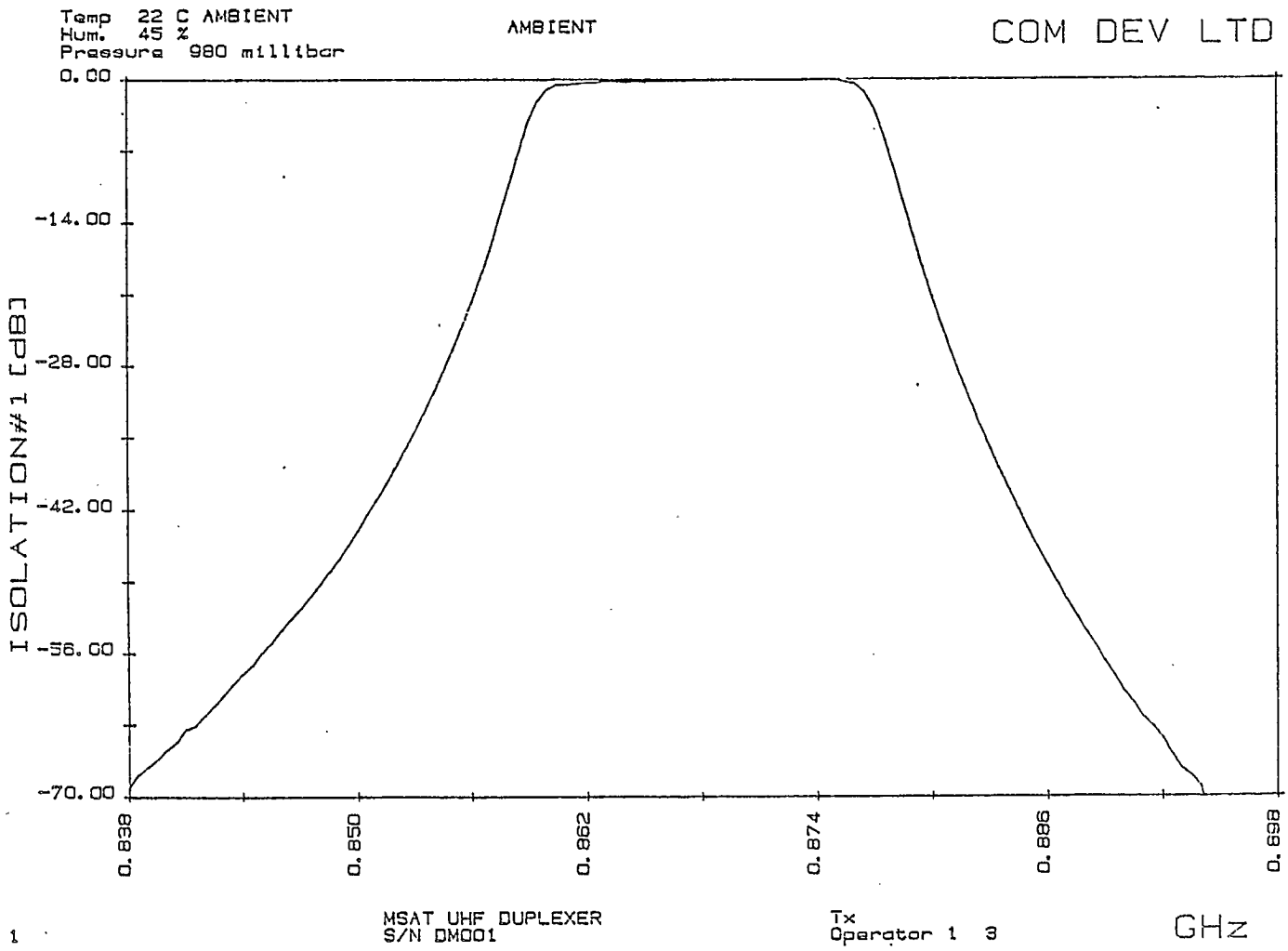
DOCUMENT No.	REV.	COM DEV
RPT/MST/2501/001	—	SHEET 45



Transmit Filter - Measured Output Return Loss Performance

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

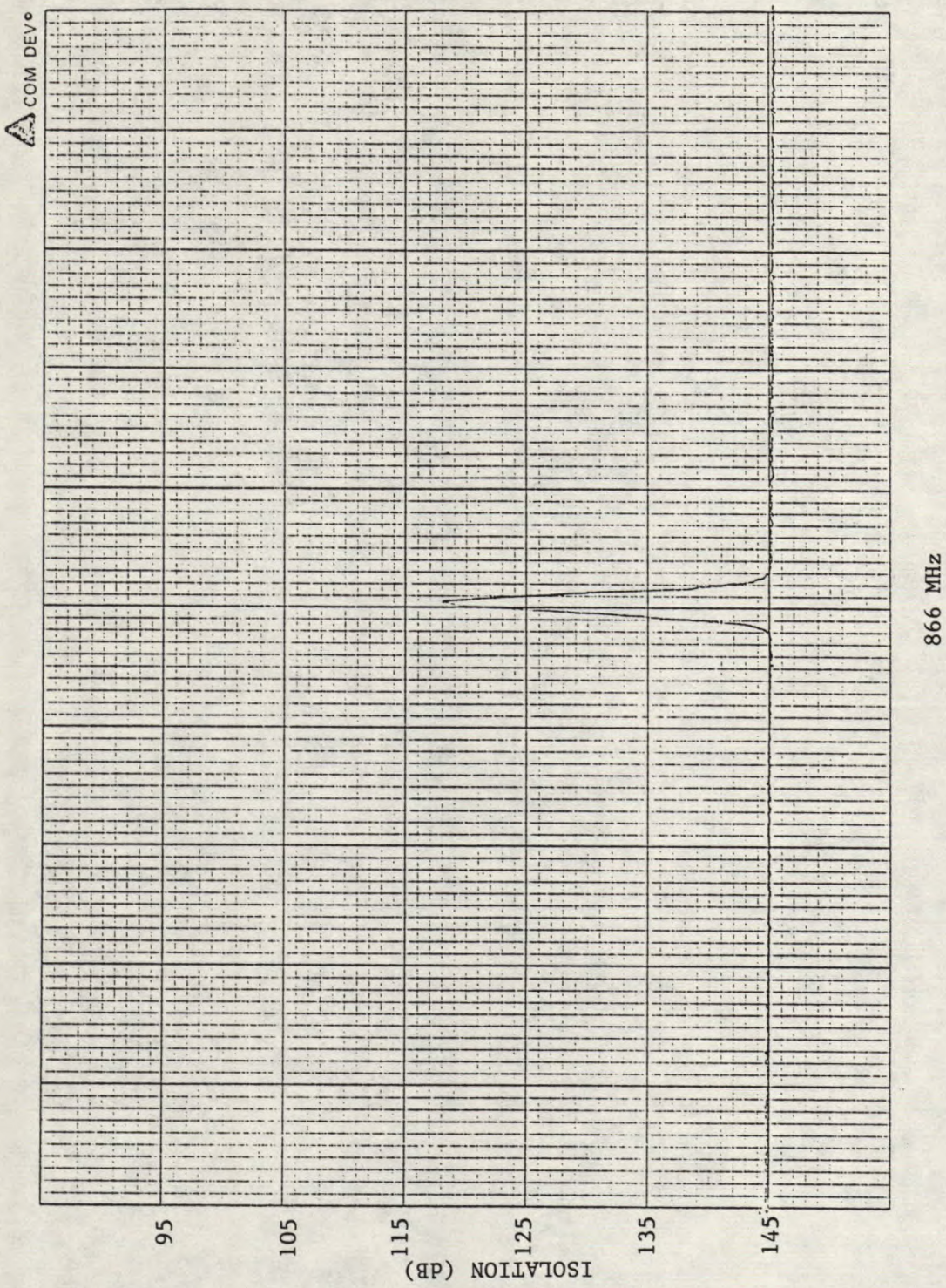
DOCUMENT No.	REV.	COM DEV
RPT/MST/2501/001	—	SHEET 46



Transmit Filter - Measured Isolation Performance

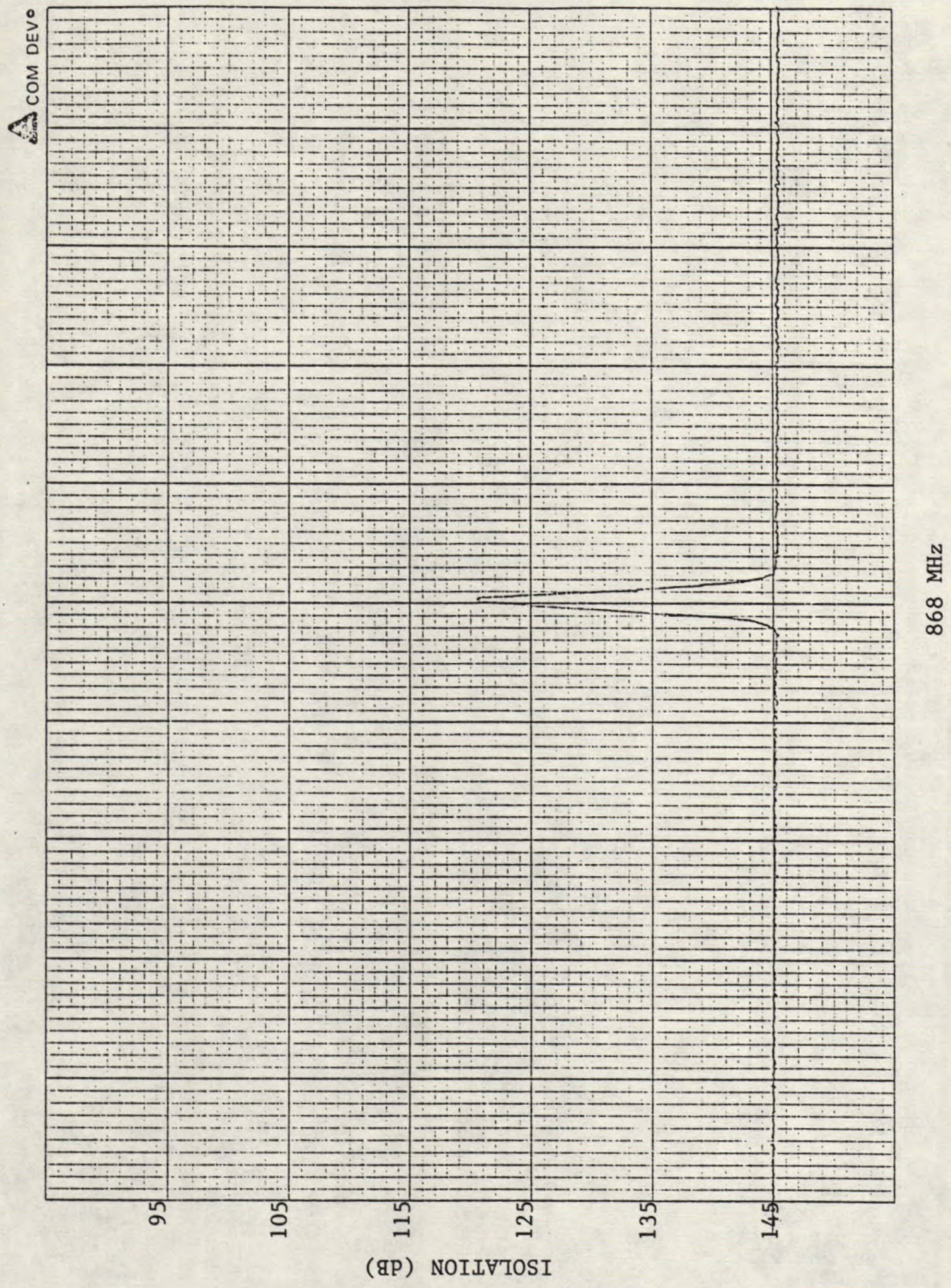
© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

DOCUMENT No.	REV.	COM DEV
RPT/MST/2501/001	—	SHEET 47



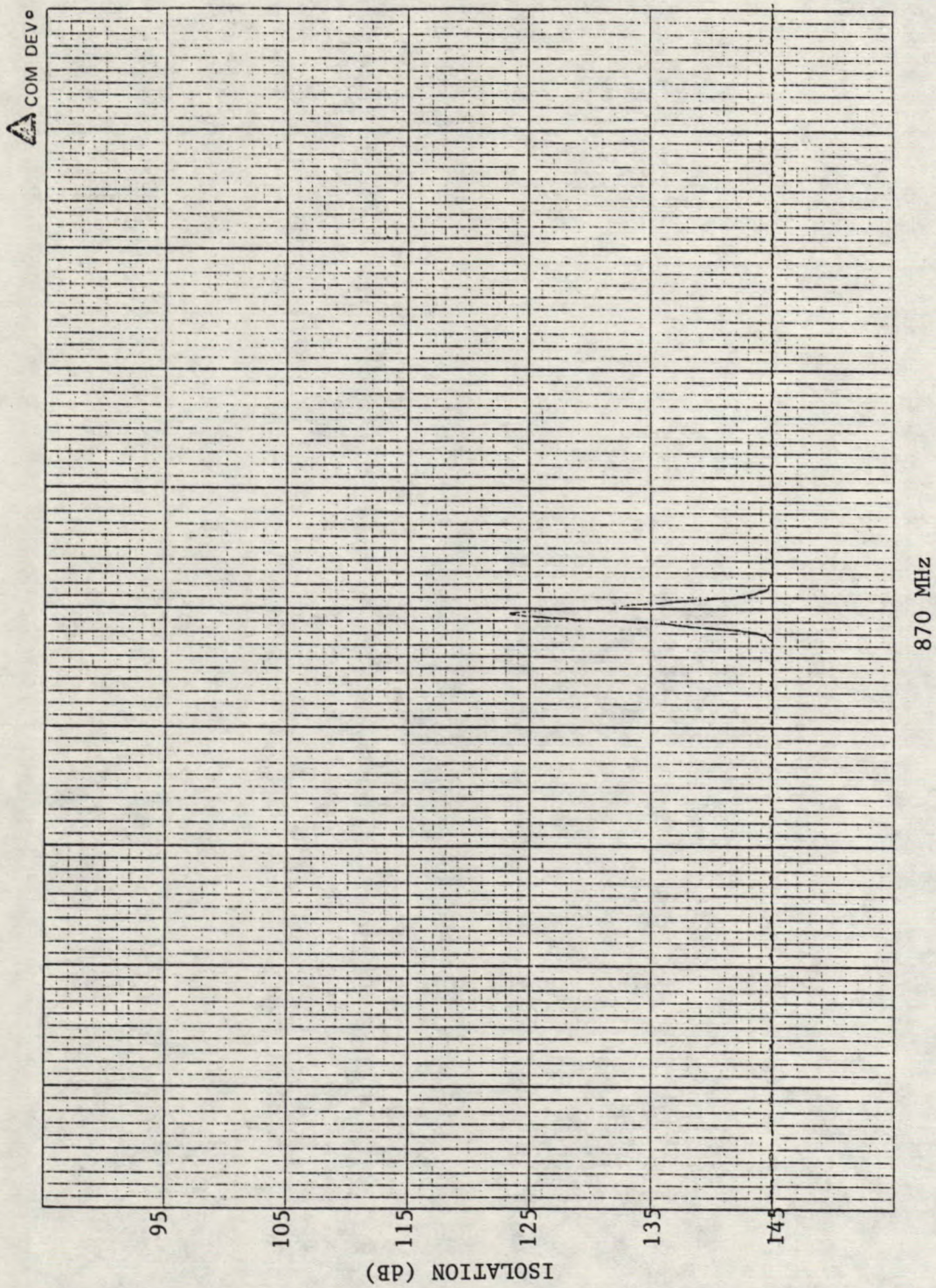
Receive Filter Rejection Spot Frequency

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.



Receive Filter Rejection Spot Frequency

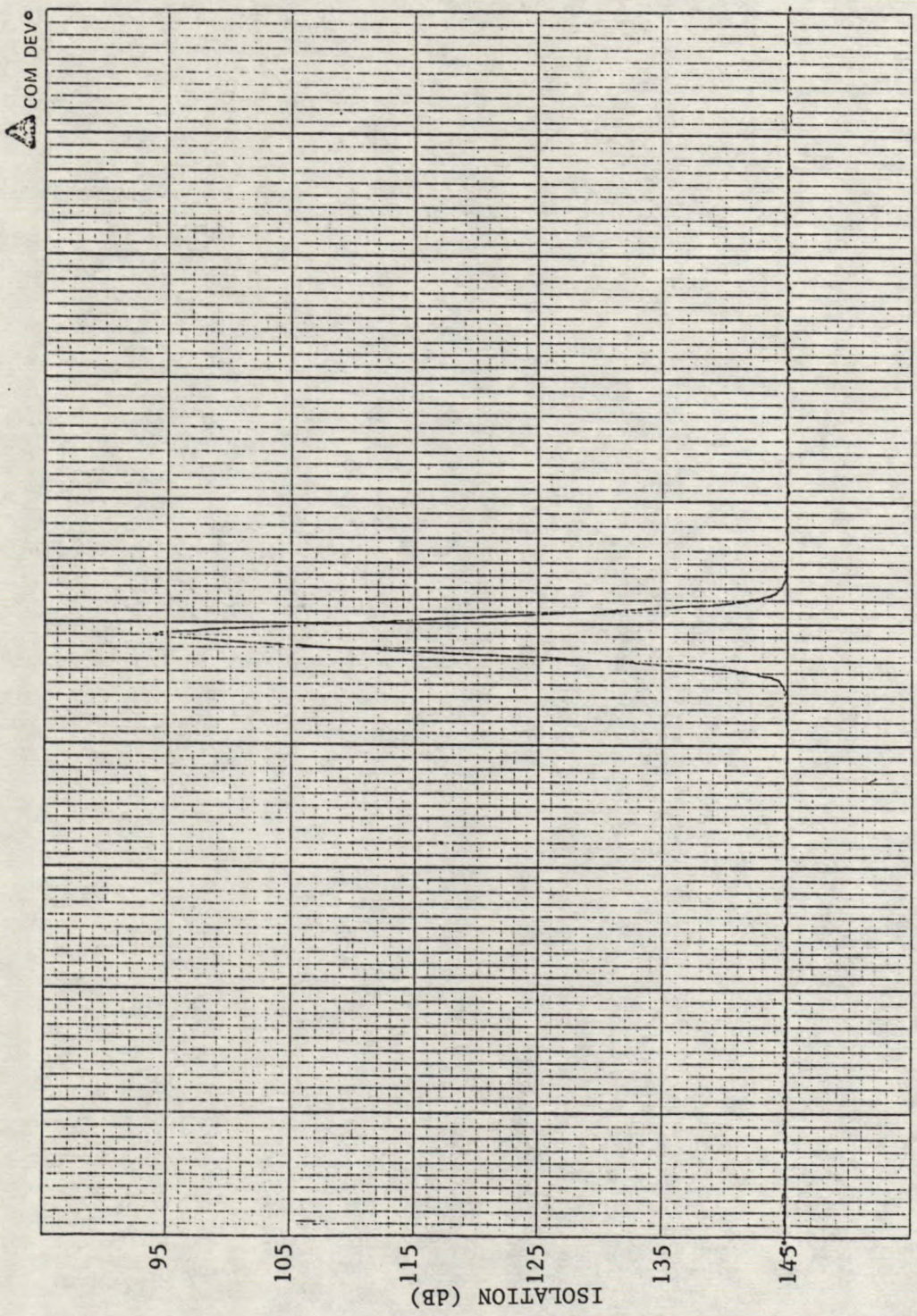
© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.



Receive Filter Rejection Spot Frequency

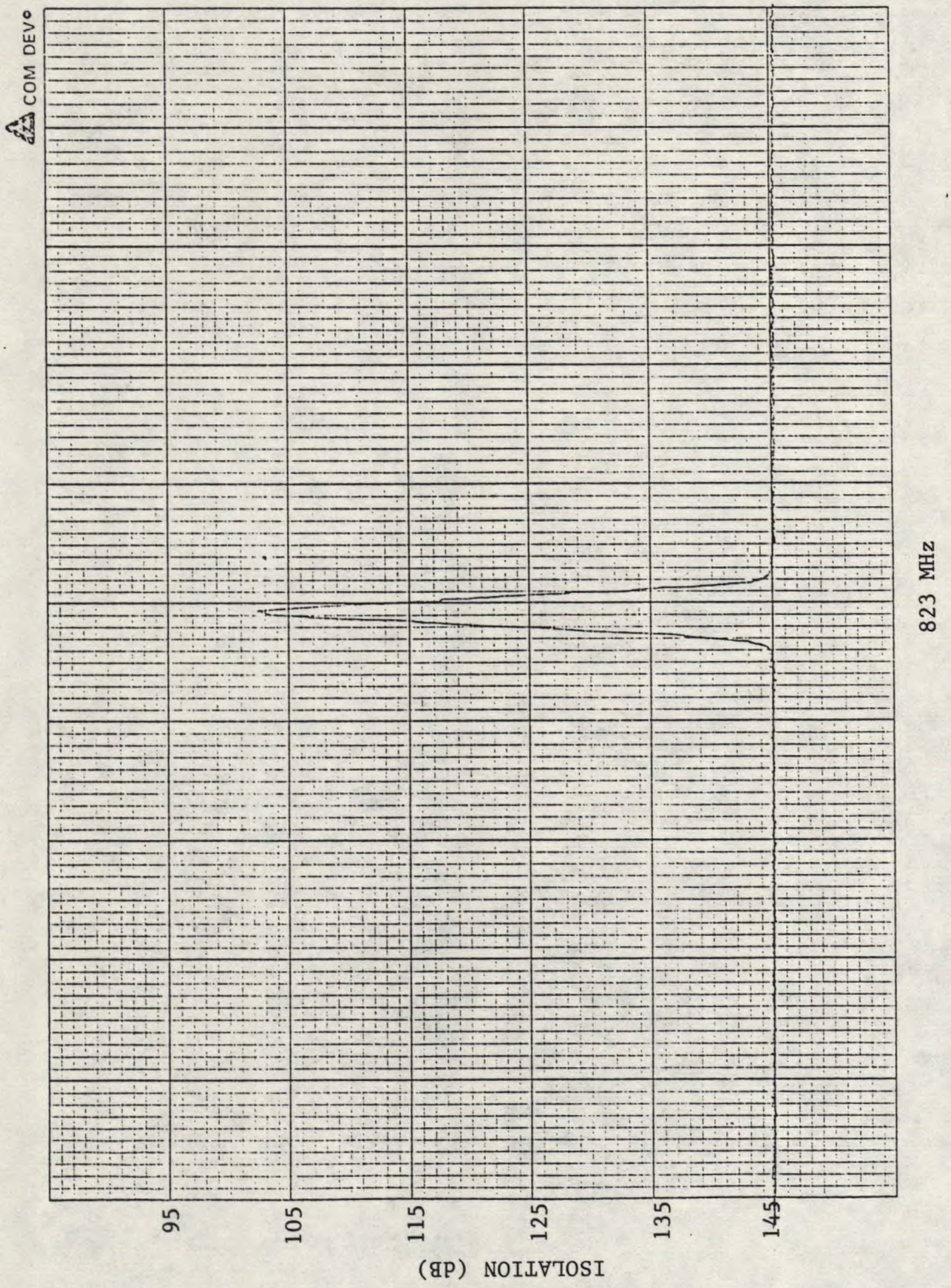
© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

DOCUMENT No.	REV.	COM DEV
RPT/MST/2501/001	—	SHEET 50



Transmit Filter Rejection Spot Frequency

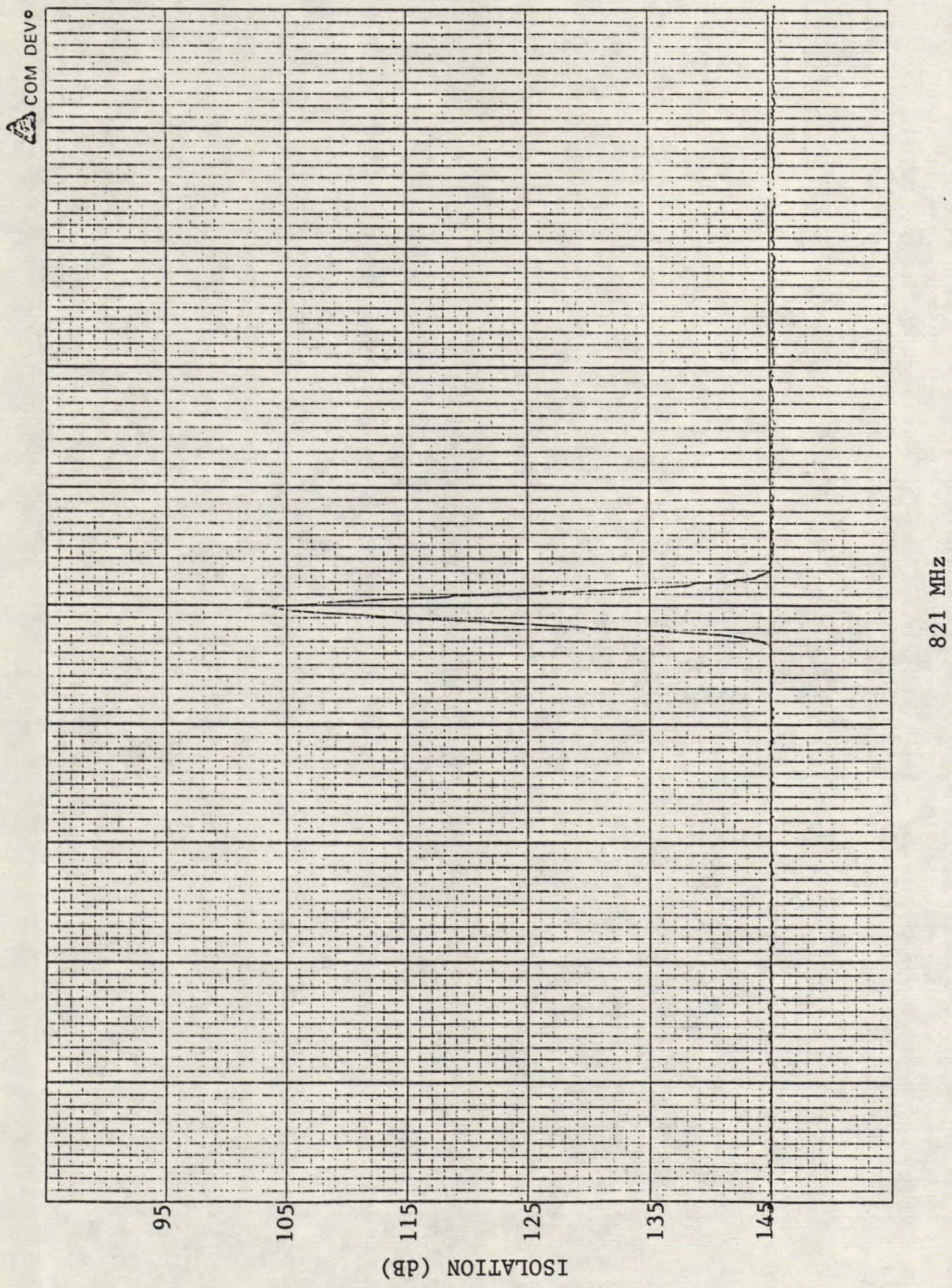
© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.



Transmit Filter Rejection Spot Frequency

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

DOCUMENT No.	REV.	COM DEV
RPT/MST/2501/001	—	SHEET 52



Transmit Filter Rejection Spot Frequency

© Her Majesty the Queen in Right of Canada (1986) as represented by the Minister of Supply And Services.

DOCUMENT No.	REV.	COM DEV
RPT/MST/2501/001	—	SHEET 53

CRC LIBRARY/BIBLIOTHEQUE CRC
TK5104.2.M8 M7334 1986

INDUSTRY CANADA / INDUSTRIE CANADA

208797

COM DEV PRODUCTS AND SERVICES
FOR
COMMUNICATIONS AND RADAR SYSTEMS

HIGH POWER MICROWAVE PRODUCTS

- High Power Filters, Diplexers, Combiners
- High Power Isolators, Circulators
- High Power Couplers, Splitters, Terminations
- Low Loss Transmit Reject Filters
- Variable Power Combiners
- High Power Antenna Co-polarized Diplexers
- Amplitude Equalizers
- Group Delay Equalizers

COMMUNICATIONS SATELLITE PRODUCTS

- Low Loss, High Order Dual Mode Output Multiplexers
- Beam Switching and Beam Reconfiguring Networks
- High Power Microwave Components and Subsystems
- Waveguide and Coax Isolators, Circulators
- Low Pass Receive Band and Harmonic Band Reject Filters
- Low Loss Preselect Filters
- Group Delay and Amplitude Equalized Input Multiplexers
- Waveguide to SMA Adaptors and Monitor Couplers
- Telemetry and Command Filters
- Variable Power Dividers

CONSULTING SERVICES

- Conceptual, hardware and systems of Microwave transponders and Communications Subsystems for Communications Satellites.
- Tradeoff analyses, layout and hardware design of high power combining and multiplexing networks for Satellite Earth Terminals.
- All software and hardware aspects of devices and subsystems involving microwave filtering networks and ferrite devices for both terrestrial and satellite communications systems.

COM DEV LTD.

155 SHELDON DRIVE,
CAMBRIDGE, ONTARIO, CANADA N1R 7H6
TEL.: (519) 622-2300 • TWX: 610-366-3164

MICROWAVE DEVICES AND SUBSYSTEMS FOR TERRESTRIAL AND SATELLITE COMMUNICATIONS