

**MSAT duplexer development :
executive summary.**

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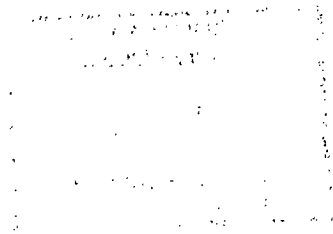
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SUMMARY

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 demonstrated 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.

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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.

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- 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.

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- 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.

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



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

All of the tasks listed above were completed.

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Tables 4.1 and 4.2 attached present the results of electrical performance tradeoffs for the transmit and receive filters respectively.

Tables 4.1 and 4.4 summarize the measured performance of the prototype unit.

The unit was subjected to a multipaction test using a 400 watt source with short circuit type test system. The unit did not exhibit any sign of multipaction until a level of 950 watts was reached whereupon multipaction occurred. Thus this unit exhibits a power handling safety margin of at least 2:1.

The PIM product level was measured in the receive band with two carriers input at 200 watts each with 1.33 MHz separation. At this level no PIM was measured down to a level of -172 dBW which was the noise floor of the test system.

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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

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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

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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

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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

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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.


5.1

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 5.1.

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 5.2. 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 5.3 outlines the performance which would be achieved based on currently available materials.

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5.2 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.

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

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ITEM	PROPOSED SPECIFICATION			
	DUPLEXER		SINGLE FILTERS	
	Tx	Rx	Tx	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 5.2: Proposed Specifications for UHF Duplexer and Single Transmit and Receive Filters

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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 5.3: UHF Receive Filter Performance Employing
Dual Mode Dielectric Resonator Filters

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