Image Cover Sheet

CLASSIFICATION UNCLASSIFIED	**SYSTEM NUMBER** 507698

TITLE

THE BOREAL LASER SOURCE

System Number:

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DSIS Use only:

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THE BOREAL LASER SOURCE

Task 1 of the Amendment to the
DSS Contract #W7701-5-3183/001/XSK

INO #97-5205-2 R N/A

INO NOI

FINAL REPORT

THE BOREAL LASER SOURCE

Task 1 of the Amendment to the DSS Contract #W7701-5-3183/001/XSK

INO #97-5205-2 R N/A

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1 Introduction

The larger DREV project regarding SAR operations includes the combination of far-infrared retroreflectors supplied to personnel and equipments at high risk together with a CO_2 laser source as scene illuminator[1]. To be of any use to SAR forces, the laser needs to be powerful (tens of watts) and as compact as possible.

A suitable laser candidate, called the Mini-Slab laser[2], has been developed recently by *Boreal Laser*. It consists in a RF driven, slab waveguide CO_2 laser supposedly capable of output power in excess of 40 watts from a very compact cylindrical volume of 6cm in diameter by 25cm in length. The associated 600W RF power supply, about the size of a litre of milk ($8x8x30cm^3$), has also been developed by *Boreal Laser*.

However, once acquired by DREV, the Mini-Slab laser failed to meet its specifications. INO was then mandated by DREV — in an amendment to the contract W7701-5-3183/001/XSK on the development of flexible retroreflectors for the far-infrared — to complete, on a best effort basis, the development of the Mini-Slab laser and to bring it as close as possible to its full specifications.

The work, detailed in the following sections, was meant to include the sealing of the laser tube, alignment of the resonator optics, management of the thermal dissipation and verification of the power supply. We will see that much more was and is still needed to achieve *Boreal Laser*'s specifications. Indeed only a mere maximum of 10 watts of unstable output power was extracted from the laser. The following sections thus end with a few recommendations regarding unforeseen modifications to the laser resonator and the power supply required in order to bring the laser to its full specifications.

2 State of the laser upon arrival at INO

The laser and its RF power supply were loaned to INO for the duration of the work along with:

- Some documentation[2]. The documentation on the laser itself covers 12 pages (excluding all the mechanical drawings) out of which 8 pages are graphs of experimental results and few pictures of sub-components. No technical details, no assembly and alignment procedures. On the other hand, the documentation on the RF power supply was truly an operating and service manual.
- Several gold output couplers and high reflectors. Some flat and some curved, many damaged (showing discoloration). We selected the best two flat optics for the experimental work.
- Two coaxial cables meant to be $\lambda/4$ transmission line. They never worked as such. They appeared to be cut to the wrong length.
- The required special CO_2 gas mixture and the special connector valve.

The crucial item missing was the RF impedance matching network. In its place was supplied the hand-drawn schematic found in the Appendix.

The laser and its power supply were inspected upon arrival at INO. It was found that:

- The laser itself was supplied with a Plexiglas window in place of its front flange and output coupler. We figured out that the window is installed when it is necessary to see directly the RF discharge and the ignition of the plasma. No high reflector was present in the resonator.
- One of the two RF feedthroughs on the top of the laser was severed flush to the laser housing. Moreover the connections to the inner electrodes were defective since it was possible to lose electrical contact by slightly jerking the feedthroughs. Good contacts were restored with tin.
- All the O-rings had to be changed. Since some grooves are non-standard some O-rings had to be made in-house. Moreover, once the cavity was under vacuum it was found that the top gas inlet leaked. The original Indium solder was then replaced by a O-ring.
- The top alumina spacer/insulator plate was broken in half. It has not been replaced because we assumed it should not affect the laser operation.
- The power supply showed all the factory-set jumper settings described in Section 2.3.5 of the *Boreal 9401A RF Power Supply Manual.*

Moreover, RF power supply was tested using the procedures stated in the manual (Section 5) and was found to behave correctly especially with respect to the VSWR inner protection. No adjustments were required.

3 Experimental work and results

3.1 DC Power interconnect

The DC Power interconnections shown in page 2-3 of the manual was followed except that for the tests we changed the two 30A circuit breakers for two 25A (Little fuse 313-3AG-25A-32V). This was motivated by the fact that under test several kinds of 30A breakers did not open under a 45A current flowing for a minute and yielded only after several seconds for currents as high as 60 to 80A. The 25A fuse resists to a 1min, 30A but blows up after 3.5min under a 35A current. No interruption occurred during experiment.

3.2 Cooling

Boreal Laser states that a <20°C water flow of 1.2liter/min is suitable for proper cooling of the power supply and the laser load. It was found however that two 2liter/min Neslab RTE-110 coolflows running 15°C water (one for the supply and one for the laser head) was insufficient during experiments (i.e. for laser output of about 10W). The experiment were carried out with one RTE-110 for the laser head and one Neslab CFT33 for the power supply.

3.3 RF Interconnect

On top of the repairs already mentioned, a good part of the experimental work was spent on the fabrication and adaptation of the missing RF matching network (given in Appendix I and reproduced in Figure 2 below) and the 1/4 wave transmission line. Great care was put in the construction of the matching network, housing and mounting plate whose technical drawings are also found in the Appendix. It was found that this network is very "layout sensitive". Indeed, the RF feeding of the laser cavity strongly depends on how the components are assembled and on the surrounding environment.

After several trials and errors in the layout of the matching network we managed to establish and hold a good plasma under a pressure of 95Torr although **using a stub connected to the centre of the coil**. However, for lower CO_2 pressures or slight jiggling of the cables, there is a net tendency for the discharge to establish itself between one electrode and the outer cylindrical housing. This implies that the load cannot be correctly balanced. This problem is believed to originate from the asymmetric design of the network, one side of the coil being connected to the variable capacitor and the coaxial cable. A possibly better design for the RF matching network is proposed in section 4.2 below.

Because of the way the power supply is to be connected to the laser head via the matching network, it is not possible to measure the Standing Wave Ratio (SWR) during experiment by inserting a bi-directional wattmeter in the 1/4 wave transmission line without disturbing it.

A modification to the power supply was then performed to measure indirectly the incident and reflected power. Two WIREPACK® couplers are used on the VSWR monitor board to sample the forward and reflected power in the main output line. Their signals were accessed from the CP1 (forward) and CP3 (reflected) "feedthroughs" and brought out on the top of the cover shield via two SMA connectors.

From the relation:

$$SWR = (Vi + Vr) / (Vi - Vr),$$

where Vi and Vr stand for the voltages associated with the forward and reflected power respectively, it is thus possible to estimate the quality of the RF coupling during operation of the laser. For example, for a strictly resistive 50Ω load, the measurements yield Vi = 16V and Vr = 0V for an SWR = 1, which correspond to an ideal coupling $Z_{(supply)} = Z_{(load)}$.

3.4 CO_2 Supply

The laser was hooked up to the CO_2 supply as shown and described in the Appendix.

3.5 Laser Alignment

Only the flat/flat resonator configuration was tried.The rough alignment of the laser optics has been done by first aligning a reference He:Ne laser with respect to the open cavity by centering the He:Ne beam on the output window alternatively placed in front and at the back of the cavity. The back reflector (and its flange) was then put in placed and aligned to return the He:Ne beam on its axis. Finally the front reflector was mounted on the cavity and aligned so that the He:Ne beam exited in the center of the output window.

The cavity was then walked until laser action.

3.6 Results

A calibrated power meter (Gentec PS-100; S/N 56679 with probe head TPM-A.1) was used to monitor the laser while walking the cavity. We succeeded in getting the laser to operate only after a great deal of efforts since the mirror adjustments are not independent and the pitches of the screws are too coarse. As stated in the laser manual, "the nature of the slab laser really requires orthogonality in the adjustment mechanism" (page 17, 3rd paragraph). And contrary to what is claimed there, modifications still need to be made on both mirror mounts.

We recorded a maximum of 10W of laser power at 85Torr of CO_2 pressure. Figure 1 shows the near field spots produced at that time. We did not succeed in obtaining a single mode profile. The alignment is rapidly lost over few minutes due to both RF matching drift and unstable mirror mounts, the mounts being particularly sensitive.

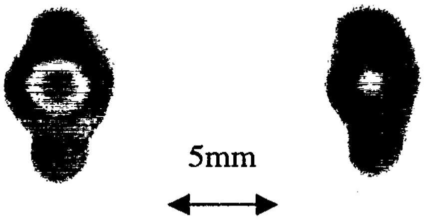


Figure 1: Two exposures of the near field spot of Boreal CO_2 Laser at ~60cm from output aperture.

At this point, operation of the laser was demonstrated at INO to the benefit of the scientific authorities from DREV. Taking into account the state of the laser, they proposed that we terminate the work by proposing modifications to the system, instead of pushing for maximum performance.

4 Recommendations

This section contains modifications to be performed on the laser systems in order to bring it to its full specifications.

4.1 Modifications to the RF Power Supply

a) The Wilkinson coupler:

The 600W RF power supply is made up of two 300W power amplifiers combined with the help of a Wilkinson coupler. Due to the larger currents involved (16A) required by these amplifiers, the DC supply line is divided into two distinct sections each deserving one of the amplifiers. It appears that a difference in the torque on the J4 connecting screws or a difference in cable impedance is sufficient to cause an imbalance in the power generated by each amplifier. This power difference is then absorbed by the 100Ω, 150W, R7 resistor (see the theory of the Wilkinson coupler in the power supply manual, section 4.3.5, page 4-4). Such a situation led to the replacement of the R7 resistor during the experiment.

To prevent damage to this resistor again and to the power supply, it is proposed that a jumper of large cross-section be placed between the DC contacts, inside the supply, just before the decoupling PCB.

b) The detection of the SWR:

The detection of the SWR is based on a comparator which disables the RF power when the DC level on the return coupler goes beyond 5.39V (see pages 5-4 and the schematics 4 of 5 of board A7.). This DC level is valid only for 50Ω loads since calibration is done using purely resistive loads. However, the CO_2 laser cavity presents a reactive load to the power supply. The calibration is then not valid since the voltages associated with the incident and reflected power are now different.

It is therefore proposed to mount an external circuit with a micro-controller (such as the 68HC711) in order to calculate the SWR and possibly display it, while automatically adjusting the SWR by a continuous adjustment of the source impedance.

4.2 RF Matching Network

The matching network proposed by *Boreal Laser,* and shown in Figure 2(a), is supposed to allow the in-phase loading of the laser electrodes while doubling the voltage to facilitate gas ionisation and plasma ignition. However it was found that the load could not be properly balanced, possibly due to the asymmetric design of the network itself.

It is proposed to match the load impedance using a toroidal transformer as shown in Figure 2(b). Such a magnetic coupling isolates the laser cavity from the RF source and should thus allow a perfect matching of the load. Moreover, partial matching could be done with the **winding ratio** of the transformer. The fine tuning is then completed using the Pi circuit which allow the raising or lowering of the load impedance as seen by the source. Finally the fact that the magnetic circuit can be sealed makes it mechanically and environmentally more robust (conductive surfaces nearby, layout of components, etc.).

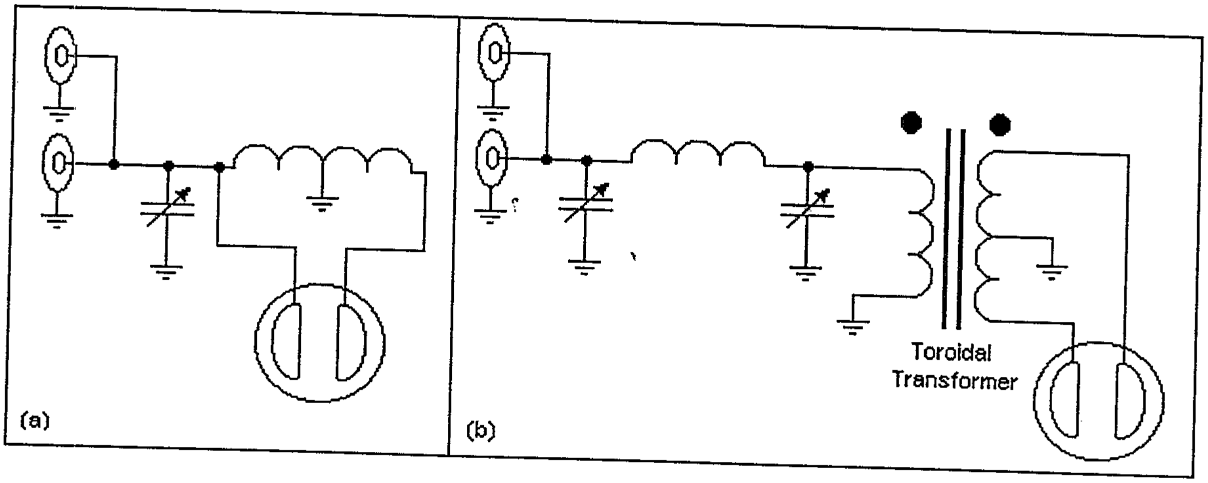


Figure 2: The RF matching network, (a) Boreal design, (b) proposed by INO.

4.3 Mirror Mounts

The mirror adjustments are not independent, the pitch of the screws are too coarse and the adjustments drift with time. To correct for the mirror adjustments, we propose the monolithic 2-axis translation adapter shown in Figure 3. In the present configuration, chosen to limit the modifications to a minimum, the adapter fits on the existing flanges. Mirror tilts are generated from lateral displacements of the tip of the mirror mount lever. Orthogonal, independent displacements are realised via differential screws pushing or pulling on the two inner rings. The rings are attached to each other and to the main frame of the adapter via 4 legs, two on each side near the corners. These assure orthogonal displacements and stability. Finally, the adapter connects to the mirror mount lever via a kind of hollow-cylinder-to-ball joint (not shown) to allow for smooth tilt of the lever without compromising the stability of the alignment.

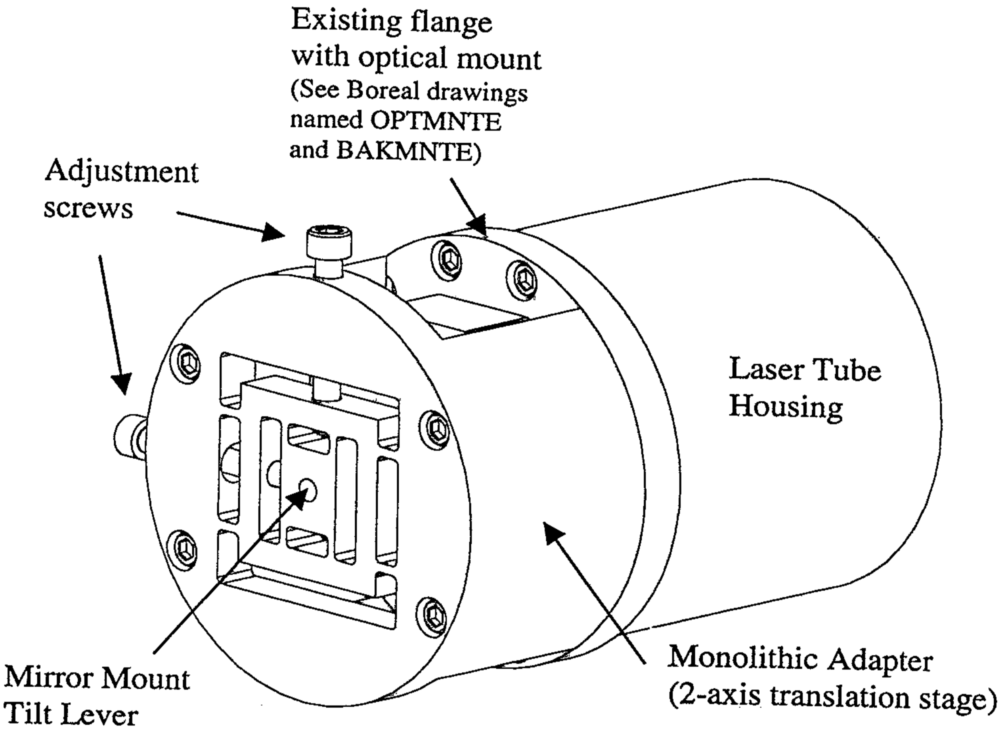


Figure 3: Schematic of the proposed 2-axis translation adapter.

References

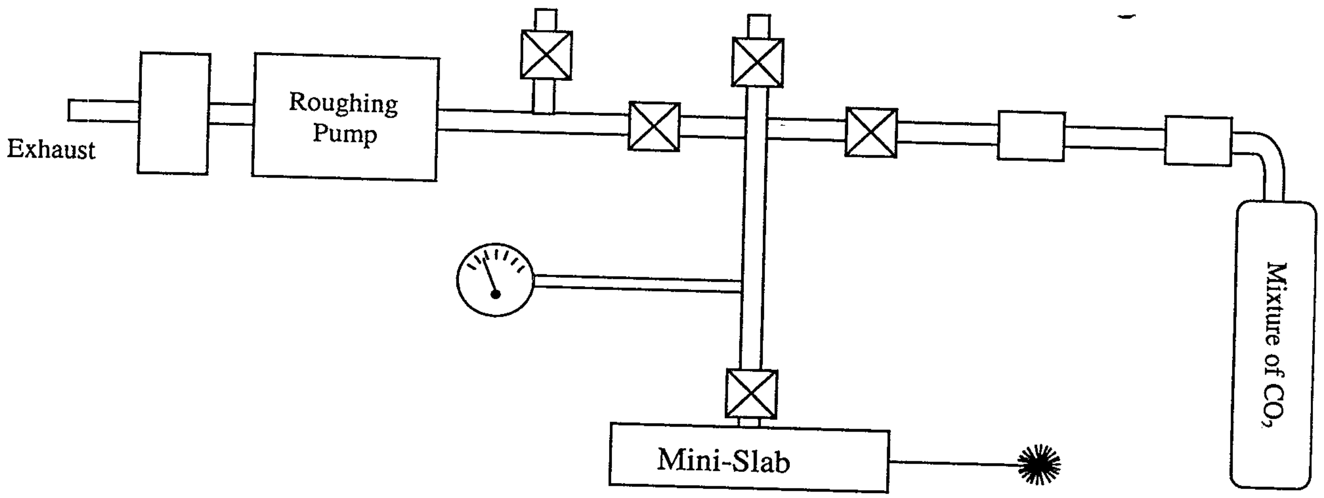
[1] Simard J.-R., Fournier G., Mathieu P., Larochelle V., “Invertigation of active imaging in the far-infrared using flood illumination”, DREV Report R-97xx, April 1997.

[2] Paulson, M. D., E. W. Badger and J. Tulip, “Search and Rescue Mini Slab Laser”, Boreal Laser, 1996, pp:1-47.

Which also includes the Boreal 9401A 600W RF Power Supply Operating and Service Manual.

APPENDIX

CO_2 Connections and CO_2 Filling Procedure



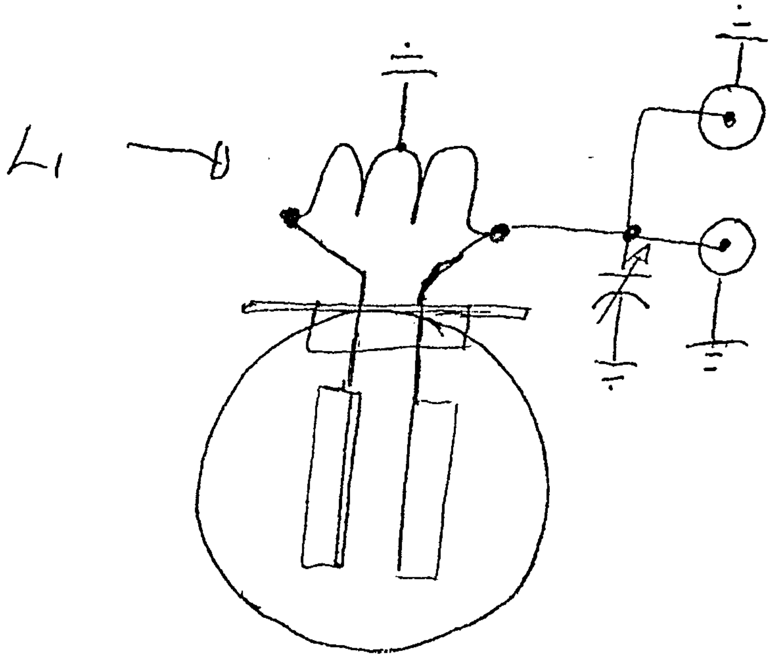
V1 : Air inlet valve
V2 : Valve for vacuum control
V3 : Laser Air inlet valve
V4 : Valve for CO_2 Control
V5 : Special valve for Laser sealing

F1 : Membrane Filter (0.2um)
R1 : Pressure Regulator 0-150psi
T1 : Oil Trap

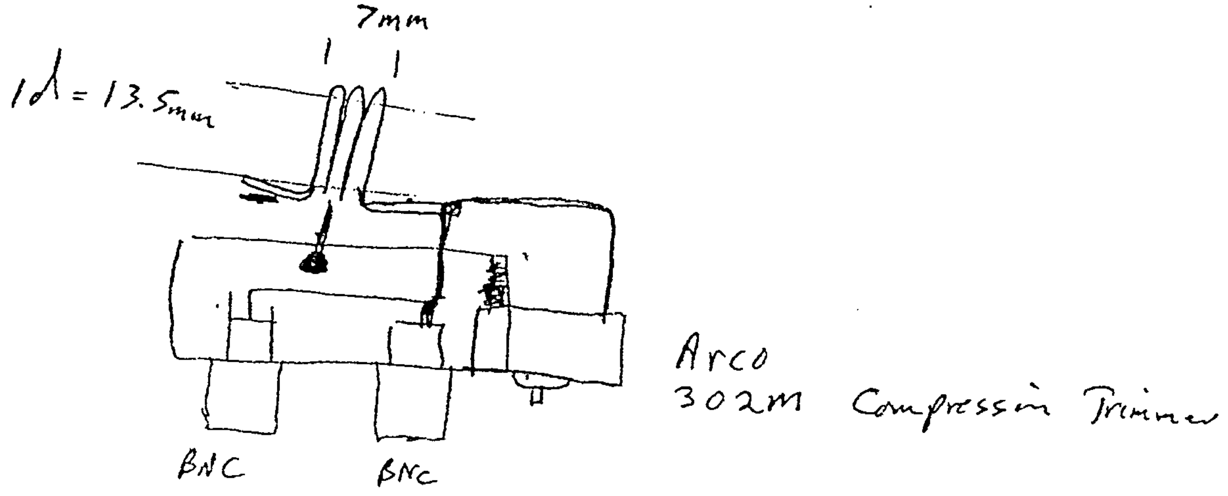
CO_2 Filling Procedure

1. Rough Pumping: V1, V3 and V4 closed
   V2 and V5 opened
   Let pump run until ~4Torr reading
2. CO_2 Filling: Set R1 to about 1psi
   Slightly close V2
   Open V4 until desired pressure (~90Torr)
   Close in order V5, V4 and V2
   Shut pump off
   Open V1 to prevent creeping of the pump oil

MiniSlab Matching Network.



L1 is 3 Turns Center tapped (~~on~~ wound on 13.5mm mandrel or 1/2") #14 wire



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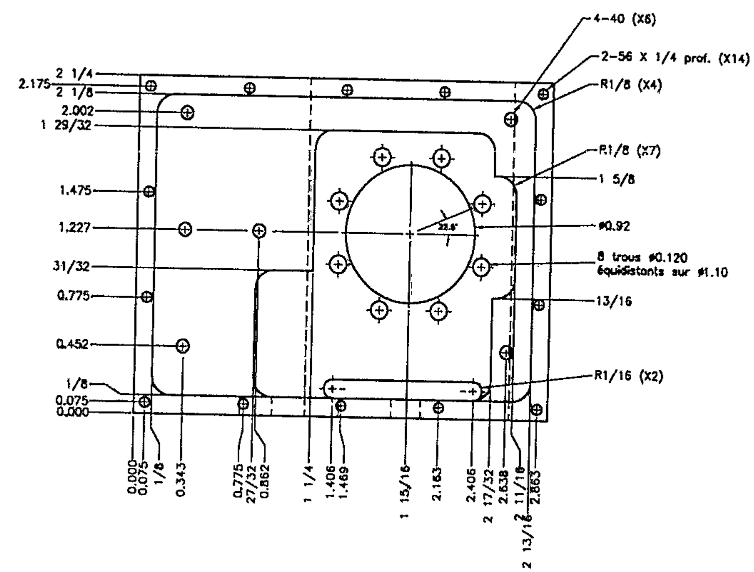

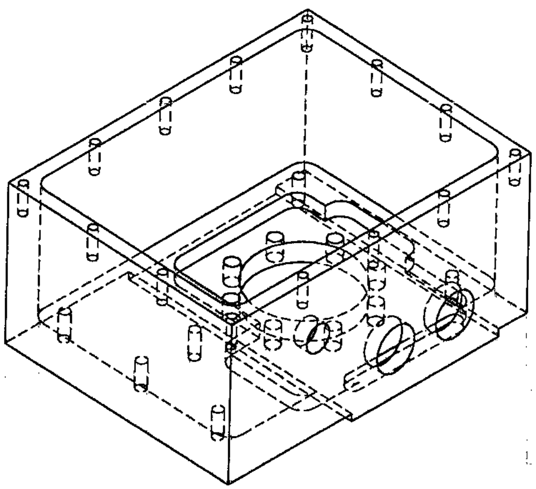

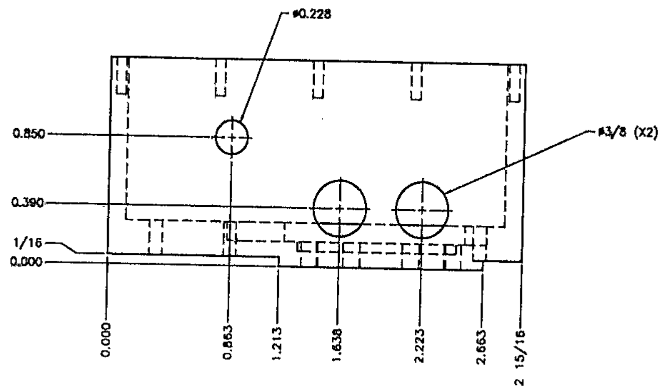

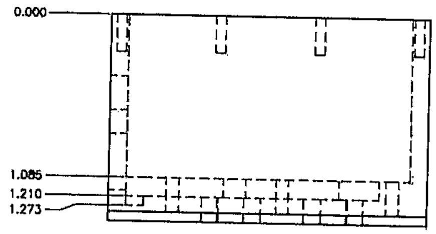

TOLÉRANCES

x/x	± 1/32"
.x	± .010"
.xx	± .005"
.xxx	± .002"
Angle à 90°	± 1/2°
Fini de surface	63√

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Boitier de l'adaptateur d'impédance

CONÇU : Marco St-Pierre | DESSINÉ : Marco St-Pierre | APPROUVÉ : André Fougères
QUANTITÉ : 1 | ECHELLE : 3/4"=1" | DATE : 11/04/97 | FEUILLE 1 de 2 | VERIFIÉ :
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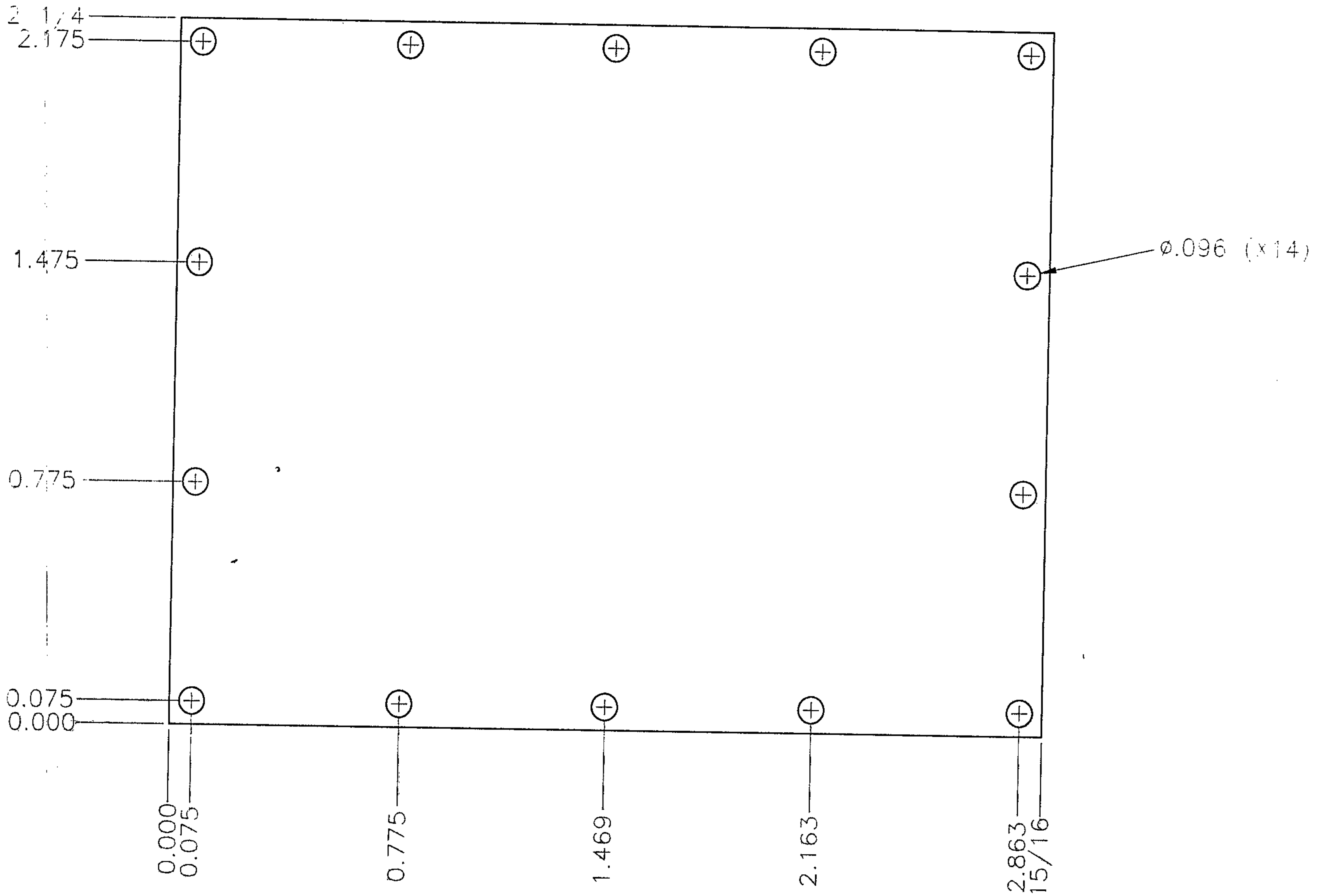
9702 | 5205 | 0002



TOLÉRANCES	
x/x	± 1/32"
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Angle à 90°	± 1/2°
Fini de surface	63

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QUANTITÉ : 1	ECHELLE : 2"=1"	DATE : 27/02/97
FEUILLE 2 de 2	VERIFIÉ :	

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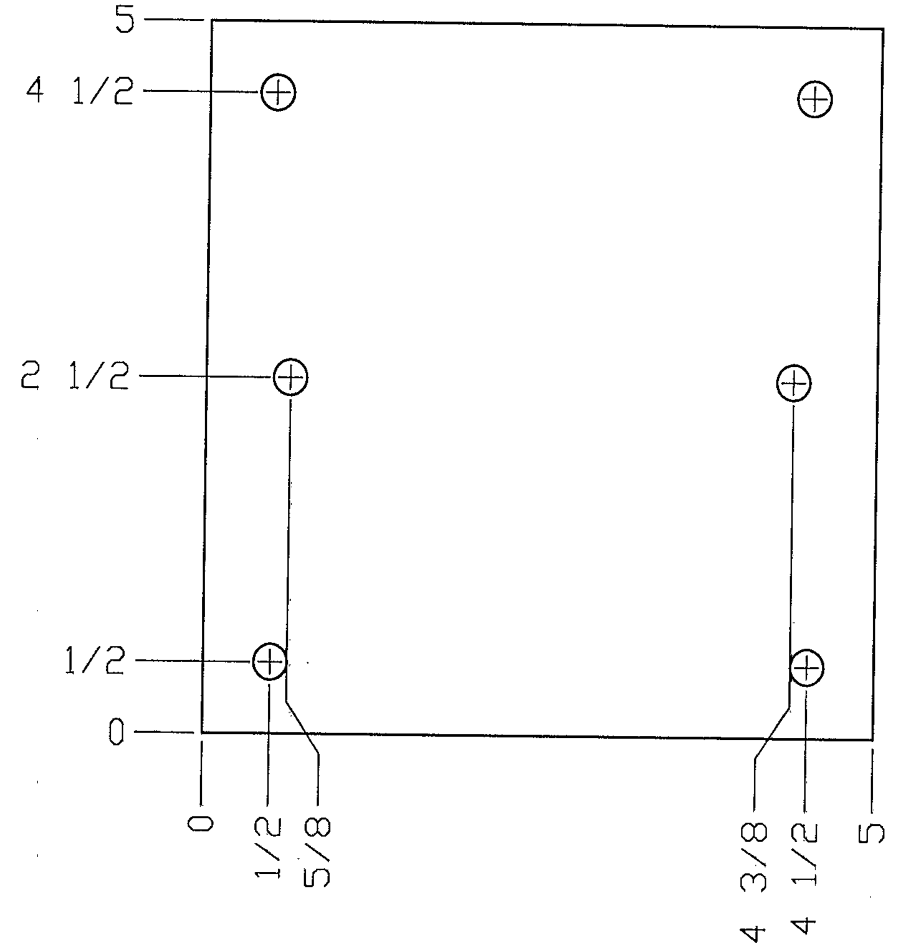

TOLÉRANCES	
x/x	± 1/32"
.x	± .010"
.xx	± .005"
.xxx	± .002"
Angle à 90°	± 1/2°
Fini de surface 63√	

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Support du Mini Slab

CONÇU : Marco St-Pierre	DESSINÉ : Marco St-Pierre	APPROUVÉ :	
QUANTITÉ : 1	ECHELLE : 1"=1"	DATE : 28/01/97	FEUILLE 1 de 1	VERIFIÉ :
MATÉRIEL : ALUMINIUM 1/4" EPAIS PL. " x " x "	0997	5205	0003	FORMAT A

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