CPRC **CCRP**

CANADIAN POLICE RESEARCH CENTRE | CENTRE CANADIEN DE RECHERCHES POLICIÈRES

TR-01-93
Evaluation of Protable Contraband Detector
Portable Microwave Dielectrometer M600P

M. Hupé, P. Pilon and M. Rumpel
Revenue Canada, Customs and Excise

TECHNICAL REPORT
June, 1992

NOTE: Further information about this report can be obtained by calling the CPRC information number (613) 998-6343

NOTA: Pour de plus ample renseignements veuillez communiquer avec le CCRP au (613) 998-6343

SUMMARY

Evaluation of Portable Contraband Detector, M600P

The Laboratory and Scientific Services Directorate of Revenue Canada, Customs and Excise conducted a laboratory evaluation of the Portable Microwave M600P Dielectrometer. The M600P was provided by R.H. Nicholls Distributors Inc., Montreal.

The M600P is a hand-held instrument producing a very low-level microwave signal which is transmitted into an object under inspection. The signal interacts with the object and a portion of the signal is reflected back to the M600P. Using an elliptical antenna, the M600P compares the reflected signal from the test object to an internally generated signal and displays the results on a digital meter. It is in this way the dielectric properties of materials are measured.

The results of numerous tests can be learned by reading this report, and have been made available to the manufacturer.

M600P Laboratory Tests

M. Hupé,
P. Pilon,
M. Rumpel

Project # 10005

June, 1992

1.0. Introduction.

The Enforcement Directorate of Revenue Canada, Customs and Excise, was recently contacted by a representative of R. H. Nicholls Distributors Inc., with information about a portable contraband detector, the M600P, manufactured by Spatial Dynamics Applications, Inc., an American company based in Massachussets. After a demonstration of the instrument at a conference in Montreal, the Laboratory and Scientific Services Directorate (LSSD) of Revenue Canada, Customs and Excise, contacted R. H. Nicholls and Spatial Dynamics Applications, Inc., to obtain an instrument for a period of time for laboratory tests.

The M600P is a hand-held instrument producing a very low-level microwave signal which is transmitted into an object under inspection. The signal interacts with the object and a portion of the signal is reflected back to the M600P. Using an elliptical antenna, the M600P compares the reflected signal from the test object to an internally generated signal and displays the results on a digital meter. In this way, the dielectric properties of materials are measured.

The depth of penetration of the microwave signal depends on the dielectric properties of the material being examined. In air, the penetration is approximately 4 feet; the depth of penetration decreases to about thirty inches for a bale of wool and to six inches for a water solution.

The instrument operates at a frequency of 600 MHz, at a wavelength of 50 cm. The response time is less than 2.5 milliseconds. The readings are displayed on a digital meter, to one number after the decimal, and an audio signal is also produced. The instrument is hand-held, weighs 4 lbs and can operate either from a rechargeable 9V battery pack or from a 120 VAC power supply. The equipment includes a belt holder for the battery pack and an ear plug and cord for the audio signal.

According to the User's Manual provided by the manufacturer, there are no safety hazards associated with the M600P. Output power levels are 1/1000th of established standard safe levels in the US.

In most applications, the M600P has been used to make relative measurements on homogeneous materials. For these materials, a change in readings from one object to another or from one area of an object to another will indicate a discrepancy in the material which may warrant further examination.

The following scenarios have been identified by the manufacturer as possible uses of the M600P:

- hidden items in a shipment of asphalt or cement blocks;

- hidden items in large rolls of plastic or bales of clothes or cotton;

- hidden items in frozen shrimps or fish;

- hidden drugs in flower boxes;

- dissolved solids in wine or any alcoholic beverage; and

- drugs in tires.

Other possible uses of the instrument have been identified on the manufacturer's target list, a copy of which has been attached as an appendix. The manufacturer also indicates that the instrument will readily differentiate water from solid materials and will pick up metal hidden behind non-metallic surfaces readily, because of the differences in dielectric properties of these materials.

A number of hints have been given to enhance the accuracy of the readings of the instrument.

- Metal objects or surfaces within two feet may affect the reading of the instrument.

- The size of the samples must be identical.

- The measurement should be taken at the same place for all identical objects.

- Ensure that the readings are being taken against a flat surface. If not, air will be included in the readings and will cause fluctuations.

- The test substances being compared must be homogeneous.

- The presence of moisture will greatly affect readings.

This report is a summary of the laboratory tests conducted at LSSD, encompassing some of the applications for use mentioned above. Some of the hints described by the manufacturer to obtain better results were also tested. The possible advantages and drawbacks of the use of this detector in a Customs environment are mentioned, along with possible changes which may make the instrument more useful to Canadian Customs officers.

2.0. Experimental Procedure.

2.1. Operation of the Instrument.

The procedure outlined in the user's manual of the M600P was followed exactly. In some cases, the advanced sensitivity procedure was followed to obtain more variation in the readings between two objects to be differentiated. The use of the advanced sensitivity procedure has been noted, where applicable.

2.2. Reading Variations of the Instrument.

The same container, containing the same material was tested in an identical manner 10 times to determine the instrument variation in readings. The following items were used:

- glass tank, with water, through a depth of 13 cm.

- glass tank, with water, through a depth of 16 cm.

- Six different cola bottles, as filled at the bottling plant.

2.3. Reading Variations as a Function of Volume.

2.3.1. Wine Bottle Filled to Different Levels.

The M600P was placed at the same position on a wine bottle filled to different levels with water. The variation in readings as a function of water level was recorded.

2.3.2. Glass Tanks.

Two glass tanks were tested to determine the variation in the readings of the M600P as a function of the level of water within the tanks. The readings were taken through a water depth of 16 cm and 13 cm. For each depth, the top of the M600P was placed at a height of 16 cm on the tank and readings were obtained for water levels of 16, 18, 20, 22 and 24 cm.

2.4. Reading Variations as a Function of Temperature.

A glass tank was filled to the same level with water at different temperatures. The M600P was placed at the same position on the tank. The readings as the temperature was varied in small increments between 5.5°C and 61°C were recorded.

2.5. Reading Variations as a Function of Containers or Surfaces.

2.5.1. Individual Bottles

2.5.1.1. Cola Bottles.

Readings were taken at the height of the top of the label of six different cola bottles (750 mL), from the same manufacturer.

2.5.1.2. Prince Blanc Bordeaux White Wine.

Readings were taken on ten different glass bottles (1.5 L, 12% alcohol) at the front of the bottle, at the top of the label.

2.5.1.3. Beau Rivage Bordeaux White Wine.

Readings were taken on 10 different glass bottles (187 mL, 11.5% alcohol) at the front of the label.

2.5.1.4. Raynal Napolean French Brandy.

Nine different frosted green glass bottles (750 mL, 40% alcohol) were measured at the front of the label.

2.5.1.5. Alpenweiss White Wine.

Nine cardboard boxes containing a silver coloured bag (4 L, 10.5% alcohol) were measured in the middle of the box with the plastic spout on the side to the left.

2.5.1.6. Adams Private Stock Canadian Whisky.

Readings were taken from the top of the label of one bottle. The glass bottle was engraved in a checkered pattern (750 mL, 40% alcohol).

2.5.1.7. Seagram's Five Star Rye Whisky.

Readings were taken on ten different glass bottles (750 mL, 40% alcohol) at the top of the label.

2.5.1.8. Romariz Port from Portugal.

These regular shaped glass bottles (750 mL, 20% alcohol) were contained within individual cardboard boxes. Measurements were done on the outside of ten boxes.

2.5.1.9. Bailey's Original Irish Creme.

Eight glass bottles (750 mL, 17% alcohol) were measured at the front of the label.

2.5.2. Reading Variations for Bottles in Line or in Cases.

2.5.2.1. Bottles Side by Side.

Bottles, filled with cola, were measured individually while standing beside one another in a line. Readings were taken at the top of the label.

2.5.2.2. Horizontal Readings of Bottles in Case.

Six cola bottles were placed in a plastic carrying case (3x2 configuration). Measurements were taken at various positions around the outside of the case, all at the height of the top of the label.

Twelve glass bottles of Meaghers 1978 Canadian Rye Whiskey (1.14 L, 40% alcohol) were contained within a cardboard box (3 x 4 configuration). The bottles had cardboard dividers in between them. Measurements were taken at various positions along the outside of the box.

2.5.2.3. Readings of Bottles From Bottom of Case.

Six cola bottles were placed in a plastic carrying case (3x2 configuration). Values were obtained from the bottom of the case. The instrument was placed at the centre of each individual bottle.

2.6. Reading Variations with Environment of Instrument.

2.6.1. Variance of Horizontal Positioning.

Six positions, at the height of the top of the label, were measured around the outside of a cola bottle.

2.6.2. Variance of Vertical Positioning.

Readings were taken on a bottle of cola. The four positions were: the base of the bottle; just below the label; at the top of the label; and at the top of the liquid level.

2.6.3. Variation of Distance Between Instrument and Bottle.

The differences in the readings were noted by varying the distance between the permanently mounted M600P and a bottle filled with water.

2.6.4. Variation of Reading Due to Proximal Interferent.

Values were measured on a bottle filled with water set flush to the permanently mounted M600P. Interferents were then placed at the side and top of the instrument and behind the bottle.

2.7. Reading Variations for Concealed or Non-Homogeneous Materials.

2.7.1. Dependence of Bottle Content.

Individual cola bottles were measured at the top of the label. The reading obtained when the bottle was filled with cola were compared to the readings obtained when the bottle was filled with water.

A wine bottle was filled with varying amounts of sugar in a 40% (v/v) ethanol solution. The maximum of 200 grams of sugar was decreased by replacing set volumes of sugar-alcohol solution with a plain alcohol solution. The readings were taken at a height of 16 cm on the bottle. Instrument sensitivities were also varied.

Measurements were performed on a 750 mL glass wine bottle containing solutions varying in ethanol concentration from 10% to 95% (v/v). The ethanol content was confirmed by hydrometry.

2.7.2. Detection of Metal Concealed Behind Wood.

Readings obtained on a piece of wood 5cm thick were compared to the readings obtained when a metal sheet (12cm x 16cm x 0.5cm) was placed behind the piece of wood. The experiment was repeated with the sheet of metal behind increasing numbers of pieces of wood.

2.7.3. Object Within an Automobile Tire.

Readings were obtained at various positions on the outside wall of an automobile tire. A plastic bag (23cm x 20cm, weighing approximately 1.5kg) of a powder (barium metaborate monohydrate) was then placed within the tire and the measurements were repeated.

2.7.4. Detection of Bag of Powder Concealed Behind Wood.

A plastic bag (23cm x 20cm, weighing approximately 1.5kg), containing barium metaborate monohydrate, was placed behind varying numbers of pieces of wood 5cm thick. Readings were compared to those obtained with the wood only.

2.7.5. Objects Concealed Within a Telephone Book.

Readings were obtained on varying thicknesses of telephone books and were compared to the readings obtained when one of the books had been cut out and the cavity filled with one of the following: a bag containing 200 g of icing sugar; a bag containing 390 g of molasses; and a bag containing 160 g of molasses.

2.7.6. Objects Behind an Office Partion Wall.

Readings were obtained on a wall made of cloth covering foam and a metal support frame, approximately 5 cm thick. The readings were repeated with a plastic bag of molasses (390 g) concealed behind the wall.

2.7.7. Objects Behind a Desk Top.

Readings were obtained on a desk top, made of wood, 4 cm thick. The readings were repeated with the following items concealed underneath the desk top: a plastic bag containing 160 grams of molasses; a plastic bag containing 200 grams of icing sugar; a plastic bag containing 300 grams of icing sugar; and a plastic bag containing 500 grams of icing sugar.

2.8. Calculations.

The mean value of a number of related readings was obtained using the formula:

$$X = (\sum X_1)/n$$

where: X is the mean value;
X_1 is the ith individual reading;
n is the total number of readings.

The standard deviation, S.D., is calculated as:

$$S.D. = (\sum (X_1 - X)^2 / n-1)^{1/2}$$

The relative standard deviation, expressed as a percentage (% RSD) is calculated as:

$$\% RSD = (S.D./X)*100.$$

3.0. Results and Discussion.

Since the instrument has been designed mostly for making relative measurements and identifying concealed materials by changes in readings from a "normal" reading, a definition of a "normal reading" must be given. The "normal range" for the purpose of this study was taken as the range spanning the lowest and the highest value obtained in a set of measurements. Any value which falls 1.0 units below the lowest number of the range or 1.0 unit above the highest number of the range was considered different from "normal". Although the lowest and highest value may be outliers, this type of analysis approaches most closely the type of analysis which would be carried out by field personnel.

Another method of comparison of results obtained in this study involves the use of the relative standard deviation, calculated as shown in Section 2.8. The % RSD was calculated to determine the variation in instrumental readings expected when like objects, containing the same material, were tested using the M600P. The % RSD obtained when tests were performed on like objects, at different positions or in different environments could then be compared to the variation caused by instrumental errors. A larger % RSD indicates that the different positions or environments contribute to the variations in readings and should be minimized, where possible.

3.1. Reading Variations of the Instrument.

3.1.1. Readings on Same Containers.

It was of interest to determine the kind of variation which can be expected from the instrument when testing the same container, filled with the same material in an identical manner. This experiment was carried out on three different types of containers: a rectangular glass tank, through 13 cm of water, a rectangular glass tank, through 16 cm of water and a Coca-Cola bottle filled with water. The readings obtained are shown in Table 1. For the same container, the worst % relative standard deviation obtained was 2.7%. This is the lowest possible error which can be expected from the instrument. In all cases, this involved a difference in readings between the lowest and the highest value of 0.3 units.

3.1.2. Readings on Various Containers.

Because the instrument will not be used to take replicate readings on the same container, the variation in readings between bottles nominally containing the same material, filled to the same level, in similar bottles was determined. A large number of different types of containers, holding different types of solutions were tested. The results are outlined in Table 2. In general, the errors are larger, probably caused by differences in the bottles themselves, in the volume contained within the bottles or on the placement of labels on the bottle. The relative standard deviations vary from 2.6 to less than 8% and the differences between the lowest and highest values obtained for the same material lie at or below 2 units, with the exception of Bailey's Original Irish Creme. The reasons for this higher variation is unknown but Irish Cremes tend to be more viscous than the remainder of the materials tested and the contents of the bottle may not be homogeneous, which may be the cause of the fluctuations seen in the readings. No values are given for Adams Private Stock Canadian Whiskey since the values fluctuated to such an extent that it was impossible to obtain a stable reading on the same bottle. The bottles were engraved in a checkered pattern and this is presumably the cause for the fluctuations.

3.2. Reading Variations with Positioning of Instrument on Same Container.

A number of tests were performed with the M600P to determine how readings varied on the same container as a function of the placement of the instrument on the container. Readings were obtained on the same cola bottle, placing the instrument at various positions on the bottle. Changing the vertical position of the instrument on the bottle caused large variations in the readings. For example, placing the top of the instrument in line with the fill line of the bottle, a reading of 3.8 was obtained. When the instrument was dropped so that the top of the instrument was in line with the top of the label, the reading was 4.4. Lowering the instrument so that the top of the instrument was in line with the bottom of the label, the reading increased to 10.6. Finally a reading of 11.1 was obtained when the bottom of the instrument was lined up with the bottom of the bottle. This gives an average reading of 7.5 with a relative standard deviation of 52%. This error is much larger than the instrumental error expected and indicates that the positioning of the instrument is important if relative readings are to be used to determine whether a material has been concealed in a container.

Readings obtained by leaving the instrument at the same height but rotating the cola bottle by 90° gave the following readings: 6.1, 6.8, 6.8, 7.4, giving an average reading of 6.8 with a relative standard deviation of 7.8%. This variation is larger than the variation obtained when the reading is taken at the same point on the same bottle (% RSD of 1.5). This is presumably caused by the presence of the label or slight modifications in the glass portion of the bottle as the bottle is rotated. The variation is much lower than that seen when the vertical position of the M600P is changed.

3.3. Reading Variations with Volume.

3.3.1. Cola Bottle.

A cola bottle was filled with water at different levels and readings were taken with the bottom of the instrument lined up with the bottom of the bottle. When the bottle was full of water, a reading of 9.7 was obtained. With the bottle three quarters full, the reading dropped to 6.7. Lowering the liquid level to the half way mark of the bottle increased the reading to 12.3. The range of values obtained is much larger than that expected from normal instrument variations indicating that, if comparative readings are to be taken, one must ensure that the fill level in the bottles is approximately the same.

3.3.2. Rectangular Glass Tanks of Different Thicknesses.

This result was corroborated by performing the same experiments with a rectangular glass tank available in the laboratory. Readings were taken at the same place on the tank with different water levels. The top of the M600P was set every time at 16 cm from the bottom of the tank. Readings were taken through two different thicknesses of water, and the results are shown in Table 3. The range of values obtained and the percentage relative standard deviation are much larger than those obtained when ten readings were obtained on the same container with the same volume. For the 13 cm thickness of water the difference between the lowest and the largest value increased from 0.4 to 3.3 units and the %RSD increased from 2.7 to 20.5. For the 16 cm thickness of water, the increases were from 0.3 to 9.0 units difference and from 1.3 to 52.9 %RSD.

3.4. Reading Variations with Temperature.

Readings were taken on a rectangular glass tank through a 13 cm thickness of water at a water level of 24 cm, at a reading level of 16 cm, varying the temperature of the water between 5.5°C and 61°C in increments of 3°C to 5°C. The difference between the lowest and highest values was 8.0 units, much larger than the difference of 0.3 units expected from instrumental error. Similarly, the % RSD increased from 2.7 to 54.2 when the temperature is allowed to change.

The readings varied between 1.7 and 9.7 with temperature but did not consistently drop or increase with temperature, as shown in Figure 1. The readings decreased quickly when the temperature was dropped from 61°C to approximately 40°C where the minimum reading was obtained. The readings then increased slightly and reached a plateau for the lower temperatures. Between the temperatures of 5.5°C and 32°C, the difference between the lowest and highest values was 1.9 units and the %RSD was 19.4, still higher than the expected experimental value. It is thus recommended that all relative measurements be taken on containers at the same temperature.

3.5. Variations with Environment of Object.

A number of experiments were performed to determine the variations in the readings when an object was inspected, with various backgrounds.

3.5.1. Readings on Cola Bottles, Isolated and in Contact with Other Bottles.

Six cola bottles were lined up on a laboratory bench, with the bottles touching each other. Ten readings were taken on each bottle and the readings were compared to those obtained on individual bottles, well separated from each other. The results are shown in Table 4. In all cases, readings on the individual bottles were higher than the readings for the same bottle in contact with other bottles. The bottles at the end of the line, i.e., with air on one side and a bottle on the other side gave readings closest to the readings for the same bottle with no background, with differences between the mean readings of 0.5 and 0.9, while the bottles in the middle of the line gave differences in mean readings of 2.1, 2.4, 1.8 and 2.1. When the bottles do not have air on both sides, the radiation is absorbed to a larger extent by the bottles of liquid, giving lower readings of reflected radiation.

3.5.2. Variations in Readings with Distance Between the Object and the M600P.

Readings were taken on a wine bottle, varying the distance between the bottle and the instrument which was mounted on a stand. As the bottle was moved away from the instrument, the readings increased, as expected since less radiation is absorbed by the liquid. The results are shown in Table 5. Thus, the same distance must be kept between the M600P and the object under investigation; in practical terms this means that contact must be made between the instrument and the object being investigated.

3.5.3. Variations in Readings with the M600P on a Case of Bottled Spirit.

The results obtained on a case holding 12 bottles containing 1.14 L of Meagher's 1978 Canadian Rye Whiskey are shown in Table 6. The readings are separated into those obtained when the instrument was placed in front of a row containing 3 bottles (4 sets of readings) and those obtained when the instrument was placed in front of a row containing 4 bottles (3 sets of readings). The change in the readings between the end row and the middle row is not as pronounced as that seen with individual cola bottles, presumably because of the presence of air between the cardboard and the bottles inside the case, and, therefore, between the bottles and the M600P.

3.5.4. Variations in Readings with Surroundings of a Bottle.

Readings were taken on a bottle surrounded by air and compared to readings obtained when someone's hand is close by, at the side of the bottle. The readings dropped from 4.9 when the bottle was surrounded by air only to 4.0 when someone's hand was at 12 cm from the side of the bottle, to 1.8 when the hand was approximately 3 cm from the bottle. If the hand was lowered over the bottle, no variation was observed. Thus, holding an object under investigation should be done by pressing with the hand, from the top of the object.

3.6. Investigations on Usefulness of M600P

3.6.1. Bottles Containing Different Materials, Individual Bottles.

Readings were obtained on six individual bottles filled with cola and compared to the reading obtained on a cola bottle filled with water. A range of values from 8.1 to 9.9 was obtained for the bottles filled with cola. The reading for the bottle filled with water was 3.9, well below the lowest value obtained previously, indicating that the instrument can differentiate these materials. A repeat of the experiment at a later date gave a range of values of 6.1 to 9.2 for the cola bottles and a value of 1.9 for the bottle filled with water.

3.6.2. Bottles Containing Different Materials, Bottles in a Case.

It was of interest to determine whether the bottle containing water could be differentiated from the bottles containing cola by taking readings on the side of a case holding six bottles. Measurements were taken at five different positions on the case, three positions through 2 bottles and two positions through three bottles, with all bottles containing cola. The numbers are shown on the left hand column of Table 7. The readings vary between 6.8 and 9.3, depending on the position of the instrument on the case. When a bottle containing cola is replaced by one containing water, the readings change, with the highest change seen when the bottle of water is closest to the instrument (values in brackets in the Table). In two rows, the reading obtained through two cola bottles was one unit or more larger than that obtained for the bottle containing water closest to the instrument. In the other row, the difference in reading was less than one unit.

The readings obtained through three cola bottles were 6.7 and 9.6. One cola bottle was then replaced by a bottle containing water. When the bottle containing water was placed at an outside position of the case, the readings obtained were 6.6 with the water bottle furthest away from the M600P and 7.0 when the water bottle was closest to the M600P. A reading of 7.3 was obtained with the water bottle placed between the two cola bottles. These values are close to the lower value obtained through three cola bottles, indicating that one cannot readily identify the bottle containing water in this manner.

Attempts were made to take readings from the bottom of the case, placing the instrument under individual bottles. The results are shown in Table 8. With the six bottles filled with cola, the readings obtained on the two middle bottles gave lower readings than the outside bottles. These results are similar to those obtained on bottles placed in line. The readings on the four outside bottles gave a mean value of 6.2 with a relative standard deviation of 23.3%, which is higher than expected if only instrument variations were occurring. The larger variation is probably caused by different amounts of air between the bottle and the case or the presence of more or less plastic material in certain areas of the case.

Readings were then obtained on the bottle containing water, placing the bottle in three different positions in the case, two outside positions and one middle position. One outside position gave a reading of 1.9, well below the range of values obtained for the bottles filled with cola; the other position gave a reading of 4.8 which is only 0.2 units lower than the lowest value obtained in the case of the cola-filled bottles. The reading obtained on the middle bottle was 1.7 units below the lowest number obtained for the cola-filled bottles and can be differentiated.

In general, individual readings at different positions on the case do not differ sufficiently to allow an operator to identify a bottle containing different materials. Thus, the use of the instrument on the outside of a case is not recommended. The use of the M600P should be restricted to obtaining readings on individual bottles.

3.6.3. Readings on Bottles Containing 40% Ethanol with Varying Amounts of Dissolved Sugar.

To determine whether the M600P could identify a bottle of alcohol in which a solid material has been dissolved, readings were obtained on a wine bottle (750 mL volume) containing 40% ethanol with varying amounts of dissolved sugar. The readings were taken at the same position on a 750 mL bottle and three readings were taken for each sugar concentration. In the original experiment, the instrument was calibrated on the bottle containing 40% ethanol, without dissolved sugar. The readings obtained on 40% ethanol with varying amounts of sugar did not vary greatly from the readings for the bottle containing only ethanol (12.8 for 40% ethanol; 10.9 for 40% ethanol containing 200 g of sugar). Thus, the advanced sensitivity procedure outlined in the Operator's Manual was followed, with the highest number being chosen for 40% ethanol, containing no sugar. There is a general decrease in readings as the sugar concentration is increased, as shown in Figure 2. The readings on the bottle containing alcohol with no sugar varied between 10.8 and 11.0. The readings obtained on the bottle containing alcohol in which 29 g of sugar had been dissolved gave a range of reading between 7.8 and 8.6. If one takes the difference of one unit as being observable on the instrument, the instrument can easily differentiate between a bottle containing no sugar and a bottle containing 29 or more grams of a dissolved solid.

This instrument could be used to determine whether the contents of the bottle have been tampered with, mostly if large amounts of solids have been dissolved in the alcohol. However, the advanced sensitivity method was necessary to obtain readings which could distinguish the bottles with dissolved materials. Although the advanced sensitivity technique was helpful in this situation, and probably could be useful in many more situations, the operator needs to know a priori, that the advanced sensitivity is required. In most Customs situations, this is not known.

3.6.4. Reading Variations with Alcohol Percentage.

The variation of the alcohol percentage on the readings obtained with the M600P was investigated by placing solutions of different alcohol contents in the same bottle and taking a reading with the M600P, at the same position on the bottle. The experiment was repeated twice and the results are shown in Table 9 and Figure 3. In the first experiment, the sensitivity of the instrument was maximized on the 95% ethanol solution. One sees an increase in the M600P readings with alcohol %, where a maximum is reached at 40%, followed by a decrease as the % alcohol is increased above 40%. The experiment was repeated by setting the sensitivity on the 40% alcohol solution and taking the readings on the remaining solutions. Those results are shown on the far right column of the Table 9.

According to the variations obtained in this preliminary study, the instrument may be useful to differentiate between bottle containing different concentrations of ethanol. It is not known however, at which point the differentiation becomes significant.

3.6.5. Detection of Metal Behind Wood Panels.

A thin sheet of metal (0.5 cm thick) was placed behind a piece of cedar, 4 cm thick. The readings decreased from 9.9 for the wood only to 2.1 for the metal concealed behind the piece of wood. When the thickness of the wood was doubled to 8 cm, there was no indication of the presence of the metal.

3.6.6. Detection of Bags of Powder in a Tire.

The readings obtained on a tire showed wide variations (range of 4.5 to 11.5) , depending on the placement of the instrument on the tire relative to the ground. Placing the instrument on the tire close to the ground gave the lower reading, presumably because of absorption of the radiation by the ground. Placing the M600P on the tire at the position furthest away from the ground gave the higher reading. Similar results were obtained when the tire was placed on a chair.

Holding the tire in the air by hand gave more consistent readings (difference of 0.5 units between the lowest and the highest reading) but this does not duplicate the situation of a Customs officer wishing to detect the presence of concealed drugs within a tire on a vehicle. Furthermore, under this test procedure, the presence of a bag containing 1.5 Kg of powder was not detected by the instrument (empty tire set to 10.0; reading obtained with the bag of powder was 10.4).

This instrument does not seem suited to detect contraband concealed in tires.

3.6.7. Detection of Bags of Powder Behind Wood.

A bag containing 1.5 Kg of powder (barium metaborate monohydrate) was placed behind a piece of wood, 4 cm thick. The readings were compared to those obtained when the instrument was sampling two pieces of wood. Although in most cases, the readings were lower for the wood and the powder than they were for the wood only, the readings did not differ greatly (2.3 vs 2.6; 2.0 vs 2.2; 1.2 vs 1.7; 1.5 vs 1.7; 2.5 vs 2.8; 1.9 vs 1.9). Similar variations were seen when the bag of powder was "hidden" behind two pieces of wood (thickness of 8 cm) . Adding a third piece of wood gave identical readings.

A 160 g bag of molasses was hidden underneath the top of a wooden desk 3.0 cm thick. The readings for the desk top varied between 9.0 and 9.6, with an average reading of 9.3, with a relative standard deviation of 2.0%, the deviation expected from instrumental error. Readings obtained with the bag of molasses hidden underneath the desk top dropped to 6.8, indicating that the instrument can be used in this type of application.

When a bag of powder was concealed underneath the desk top, the efficiency of the instrument dropped. Readings for the desk top ranged between 8.3 and 8.9 while a bag containing 200 g of icing sugar gave a reading of 8.2. Similar results were obtained with a 300 g bag of icing sugar. In another experiment, the weight of the icing sugar was increased to 500 g. The instrument was calibrated on the desk and the range of readings for the desk top varied between 10.0 and 10.7. The area of the desk with the sugar gave a reading of 9.4. Thus, even at 500 g, the readings are less than 1 unit away from the expected range.

3.6.8. Detection of Bags of Powder, Molasses, in a Book.

Readings were obtained on a number of telephone books, each book with a thickness of 3.5 cm. The average reading was 1.5 with a relative standard deviation of 16%. This is higher than the deviation expected when considering instrumental error. The range of values for the books was 1.2 to 1.8. A hole 10 cm X 15 cm, 3 cm deep, was cut out of one book. The altered book, with an empty cavity gave a reading of 3.4. When 200 g of icing sugar were used to fill the cavity, the reading on the M600P remained at 3.4, indicating that the instrument will identify powder concealed inside a book.

Replacing the icing sugar by a bag of molasses weighing 390 g changed the reading to -1.1, again indicating that the presence of a liquid material will be detected.

3.6.9. Detection of Bag of Molasses Behind Office Partition.

Tests were performed on an office partition wall, made up of cloth covering a foam support, all held in a metal support frame. Measurements were taken every,5 cm,.moving the M600P horizontally along the wall. A bag containing 390 g of molasses was concealed behind the wall. Readings on the cloth and foam varied very little as a function of distance from the metal support until the instrument was over the metal support (average reading on the foam and cloth was 10.1 with a relative standard deviation of 2.2%, in the range expected when instrumental errors are considered). The values ranged from 9.8 to 10.6. When the reading was taken over the metal support, the reading dropped to 2.8. The reading obtained when a 390 g bag of molasses was behind the wall was 9.2. This reading is less than 1.0 unit below the lowest value for the wall and it may not have been detected.

4.0. Conclusions and Recommendations.

Fluctuations of readings caused by the instrument on different bottles or containers with nominally the same content lead to a difference between the lowest and highest value of a maximum of 2.0 units, in most cases. This corresponds to a relative standard deviation of less than 8%. Exceptions were seen, such as Bailey's Irish Creme, where the error was larger, and in some bottles with checkered glass patterns, where no stable reading could be obtained.

In order to get these low variations and to have a chance to detect containers with contraband, all comparative readings on containers should be made at the same position, from container to container, should be made on containers holding the same volume, at the same temperature. Failure to do so may lead to a reading on the instrument resulting in a false alarm.

To obtain reproducible readings on containers holding the same material, the background should be the same; this includes the position of a hand which may be holding the object under inspection.

The contents of bottles or containers should be verified on single bottles or containers; results obtained on bottles in a case are not reproducible.

When looking at single containers, the instrument could differentiate between bottles of cola and water, bottles containing alcohol only and bottles containing alcohol in which sugar had been dissolved. Different readings were also obtained on bottles containing alcohol solutions of different concentrations. In some cases, however, the advanced sensitivity method was necessary to obtain readings which could distinguish the bottles containing different materials. Although this technique is useful, the operator needs to know before hand that the advanced sensitivity is required. In most, Customs situations, this is not known.

The instrument could detect a sheet of metal behind 4 cm of wood, a bag of molasses behind 3 cm of wood, and bags of powder or molasses inside a book which had been cut out.

The instrument could not detect a bag of powder inside a car tire; furthermore, inspection of the tire itself led to a wide variation in readings. A bag of molasses behind an office partition was not detected. Although the appendix indicates that finding items in foam will be easy, it is pointed out that the shape of the foam is important and this may be the cause for not detecting the molasses in this case. A bag of powder behind a desk top or a piece of wood was not detected. The appendix indicates that an experienced operator should be able to find hidden items in a wooden wall but this will probably require the advanced sensitivity setting. This again brings up the discussion on the advanced sensitivity setting, outlined above.

On an operational note, the constant high-pitched sound coming from the instrument, whose pitch is linked to the numbers on the display and is helpful in noticing variation, should be replaced by an alarm which would only sound if the variation of the readings on the display is larger than an accepted variation.

Acknowledgments.

We would like to thank Mr. Clint Seward of Spatial Dynamics Applications and Mr. Mike Lee of R.H. Nicholls Distributors Inc. for the use of the M600P. We would also like to thank the Liquor Control Board of Ontario for allowing us to make measurements at their Bank Street Store in Ottawa.

Table 1. Variations in Readings of the Instrument. Readings on Same Containers.

Reading	Rectangular water tank, 13 cm of water	Rectangular water tank, 16 cm of water	Coca-Cola bottle (750 mL)
1	5.4	7.2	6.4
2	5.5	7.4	6.5
3	5.4	7.2	6.5
4	5.4	7.3	6.5
5	5.4	7.4	6.6
6	5.7	7.3	6.3
7	5.5	7.3	6.5
8	5.7	7.1	6.6
9	5.8	7.2	6.7
10	5.5	7.2	6.6
Mean	5.5	7.3	6.5
STD	0.1	0.1	0.1
% RSD	2.7	1.3	1.5

Table 2. Variation in Readings of the Instrument. Readings on Various Containers.

Contents (No. of containers)	Range of values	Mean	Standard Deviation	Relative Standard Deviation
Prince Blanc, Bordeaux White Wine, 1.5 L bottles (10)	10.2 - 11.2	10.7	0.3	2.6%
Beau Rivage, Bordeaux White Wine, 187 mL bottles (10)	10.0 - 11.3	10.5	0.4	4.0%
Raynal Napoleon French Brandy, 750 mL bottles (9)	9.4 - 10.4	9.8	0.3	3.1%
Alpenweiss White Wine, Cardboard Boxes, 4L (9)	8.2 - 9.3	8.7	0.4	4.4%
Adams Private Stock Canadian Whiskey, 750 mL bottles,	------[a]	---	---	---
Seagrams Five Star Rye Whiskey, 750 mL bottles (10)	8.5 - 10.5	9.2	0.7	7.8%
Romariz Port, 750 mL bottles in individual boxes (10)	8.9 - 10.9	9.7	0.6	6.5%
Bailey's Original Irish Creme, 750 mL bottles (8)	7.9 - 11.8	10.4	1.3	12.2%
Coca-Cola, 750 mL bottles (6)	6.4 - 8.1	7.3	0.6	7.8%

[a] Values fluctuated, impossible to obtain a stable reading.

Table 3. Reading Variations with Volume, Through Glass Tanks of Different Thicknesses.

Water Level (cm)	Thickness of Water	
	13 cm	16 cm
16	5.4	2.9
18	4.4	11.9
20	6.3	5.2
22	7.7	5.0
24	5.8	7.3
Mean	5.9	6.5
STD	1.2	3.4
% RSD	20.5	52.9

Table 4. **Readings on Cola Bottles, Isolated and in Contact with Other Bottles.**

Bottle #	Bottle Isolated		Bottle between two bottles		Bottle beside one bottle	
	Range of readings	Mean	Range of readings	Mean	Range of readings	Mean
1	7.3 - 7.6	7.4	-------	---	6.7 - 7.2	6.9
2	7.1 - 7.9	7.5	5.2 - 5.6	5.4	-------	---
3	7.5 - 7.7	7.6	4.9 - 5.4	5.2	-------	---
4	6.3 - 6.7	6.5	4.5 - 5.1	4.7	-------	---
5	8.1 - 8.4	8.3	6.1 - 6.4	6.2	-------	---
6	6.7 - 7.0	6.9	-------	---	5.7 - 6.4	6.0

Table 5. Variations in Readings with Distance Between the Object and the M600P.

Distance (mm) between bottle and M600P	Reading
0	4.9
2	6.6
3	7.9
5	9.0
8	11.8
11	12.9 (saturated)[a]

[a] Highest value which is displayed on the instrument.

Table 6. Variations in Readings with the M600P on a Case of Bottled Spirit.

Number of bottles	Reading
Three (outside row	12.6
Three (middle row)	10.2
Three (middle row)	10.2
Three (outside row	10.8
Four (outside row)	10.4
Four (middle row)	10.3
Four (outside row)	10.9

Table 7. Readings Obtained on Bottles Containing Different Materials, Bottles in a Case.

Reading through:	reading (Cola)	reading (Cola and water)
Two outside bottles	9.3	9.2 (6.9)*
Two middle bottles	6.8	5.6 (5.6)*
Two other outside bottles	7.2	7.1 (6.5)*

* Values in brackets are those obtained when the bottle containing water is closest to the instrument.

Table 8. Readings Obtained on Bottles in a Case, from the Bottom of the Case.

Position of Bottles		Range of Values Filled with Cola	Value Filled with water
Outside row		5.0 - 8.2	1.9, 4.8
	Mean:	6.2	
	RSD:	23.3%	
Middle row		2.5, 2.8	0.8

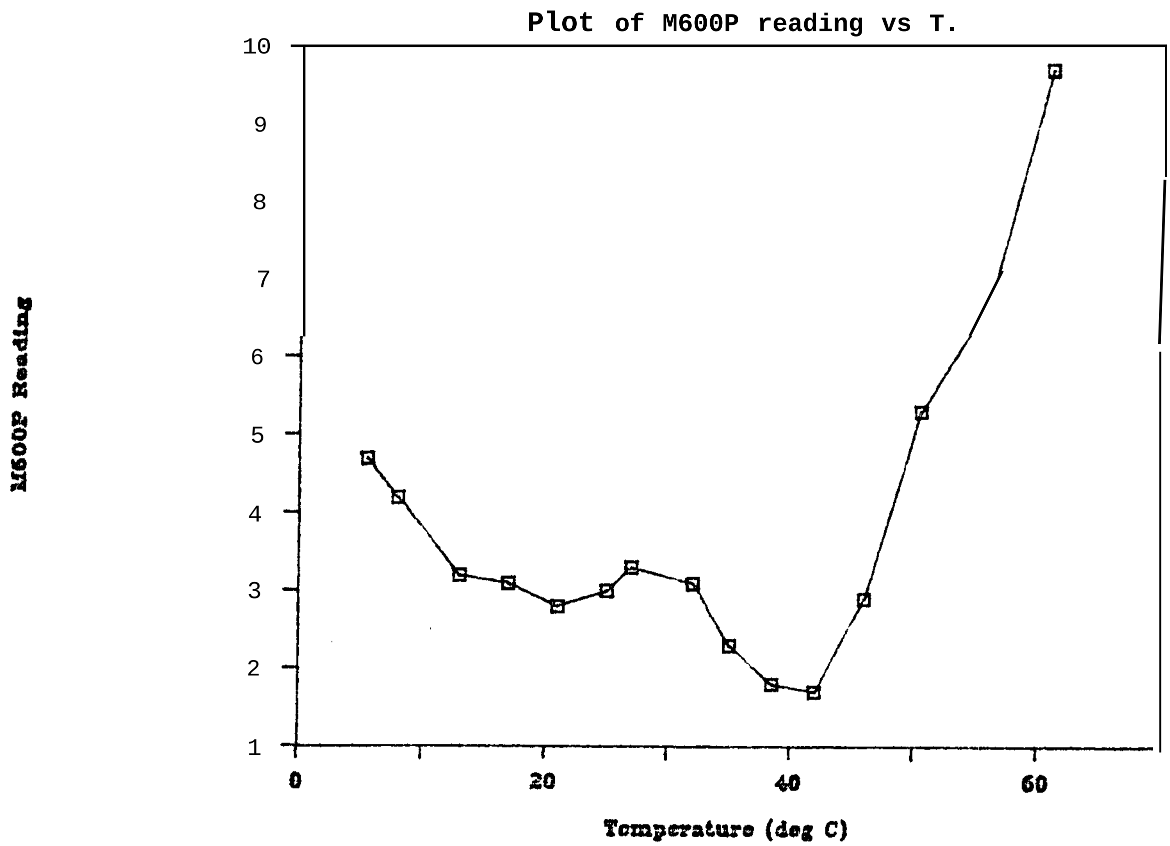
Table 9. Reading Variations with Alcohol Percentage

Alcohol % (v/v)	M600P Reading (a)	M600P Reading (b)
95	10.1	3.3
75	7.3	3.7
40	13.1 (saturated)	10.3
25	4.2	-2.1
10	-8.8	-10.5

(a) The instrument was calibrated on the 95% ethanol solution.

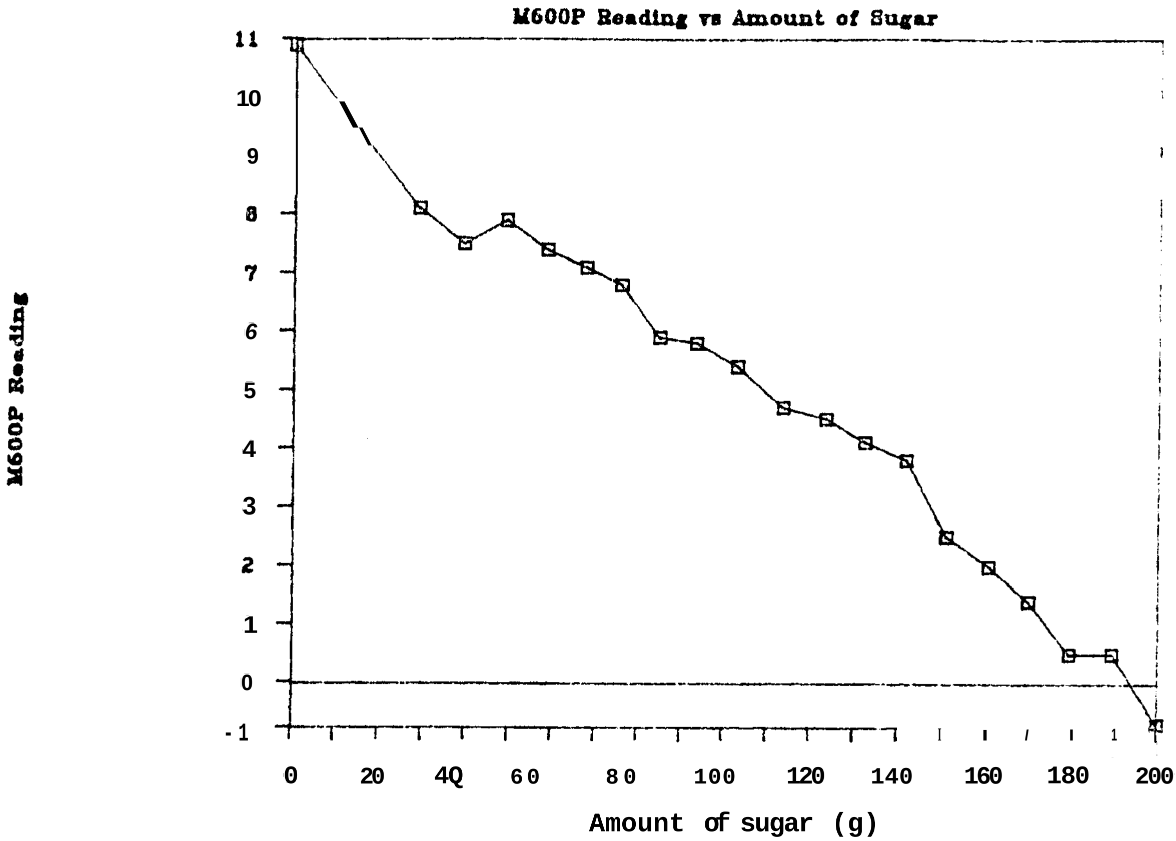
(b) The instrument was calibrated on the 40% ethanol solution.

Figure 1



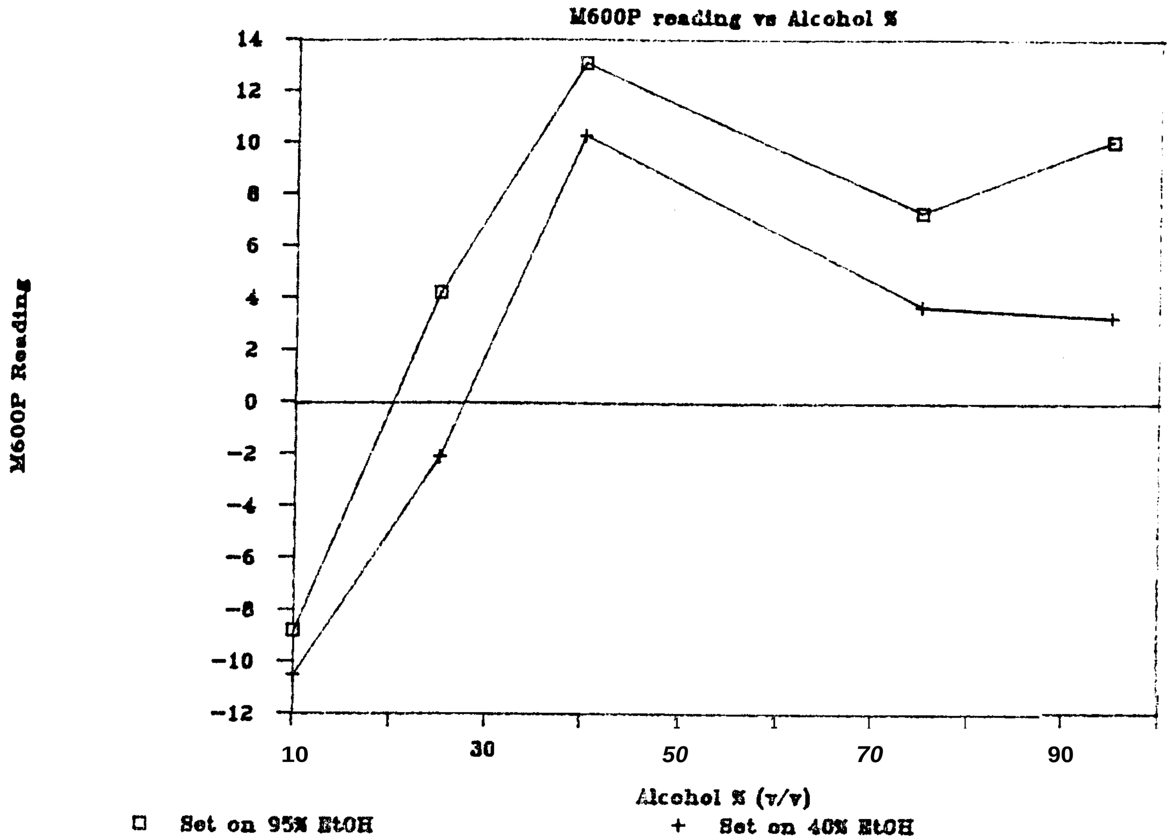
Plot of M600P reading vs T.
10
9
8
7
6
5
4
3
2
1
0
20
40
60
M600P Reading
Temperature (deg C)

Figure 2



M600P Reading vs Amount of Sugar
11
10
9
8
7
6
5
4
3
2
1
0
-1
M600P Reading
0
20
4Q
60
80
100
120
140
160
180
200
Amount of sugar (g)

Figure 3


M600P reading vs Alcohol %
M600P Reading
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
10
30
50
70
90
Alcohol % (v/v)
□ Set on 95% EtOH
+ Set on 40% EtOH

Appendix

TARGET LIST: M600 DIELECTROMETER FROM SPATIAL DYNAMICS APPLICATIONS
JAN 1992

EXPLANATION: Dielectric Detection is effective for many drug, contraband, and explosive detection applications.

The following targets have been tested and analyzed. Effectiveness is noted as:

- E for excellent: best and easiest use.
- G for good: helpful to a normal operator with experience.
- M for maybe: helpful to an advanced operator.
- N for no: Not helpful.

EXPECTED TARGET RESULTS:

ALCOHOL, finding undeclared alcohol in bottles or non-metal containers: E: when water in a bottle is replaced in part by alcohol, the change is easy to measure, since water has a dielectric constant of 80, and alcohol is 30.

ASPHALT, finding metal, drugs, voids: E to G: see concrete.

BOATS: M: Boats are often fiberglass or wooden, which can be interrogated with microwaves. The shape of the boat is such that it often takes an experienced operator to interpret the results.

BOAT FURNISHINGS: G: Boat furnishings are made of foam which is a good hiding place. The M600 will "see" through the foam and find hidden items. Experience will help to interpret the results.

BOTTLES, Alcohol: E: when water has been replaced with alcohol, the difference will be easy to spot.

BOTTLES, Cocaine dissolved in: E: set the instrument to read for a good bottle, and any bottle with dissolved cocaine in it will give an unmistakable response to it. This was the basis of the famous Pony Malta case in Miami in 1991.

BOTTLES, Explosives, liquid: E: when water has been replaced with a petrochemical or nitromethane, the difference is easy to spot.

BRICKS, finding metal, drugs, voids: E to G: see concrete.

CAMPERS: M: An experienced operator will find items hidden behind panels, and under flooring (but not through metal).

CARS: M: an experienced operator can find items hidden in seats, and behind panels. This takes work. Microwaves will not go through metal.

CERAMIC TILES, finding metal, drugs, voids, water: E to G: see concrete. A good case was made by Customs in finding drugs in a metal box hidden within a large pallet of ceramic tiles.

CHEMICALS, Identification: G: screening same sized containers to determine which chemical is inside. Good for plastic 55 gallon drums. Note 3.

COMMERCIAL ITEMS: G to M: many boxes of the same size and contents are a natural, they should read the same. It will take an experienced operator to select when this will be useful.

CONCRETE, Drugs or explosives inside: G: concrete is dense with E' = 9, while drugs have E' = 2.

CONCRETE, Metal inside: E: will find rebar, wire, metal objects, and metal boxes.

CONCRETE, Voids: G: concrete is dense with a dielectric of 9 while a void is air with a dielectric constant of 1.

CONCRETE, Water: E: concrete has a dielectric of 9, while water has a dielectric constant of 80. A small amount of water in dry concrete will give a large response.

EXPLOSIVES: finding them hidden : this is the similar to finding drugs since the dielectric constant of drugs and explosives is similar. Refer to individual searched items.

FALSE COMPARTMENTS (In fiberglass boats, campers, walls, etc.): M: The M600 can be helpful for an experienced operator.

FIBERGLASS: E: the microwaves will penetrate fiberglass easily.

FISH, FROZEN: finding drugs: M: for individual fish the volume of the fish will change from fish to fish. An experienced operator should be able to find a kilo of cocaine in a frozen fish by comparing to other frozen fish that are known to be "good".

FLOWERS: M to G: testing has shown that the dielectric response of drugs is markedly different from flowers. A kilo of drugs in a flower box has been shown to be easy to detect. Drugs hidden in green straws to simulate stems would be detectable since the drugs are dry and are replacing the water based flowers.

FOAM: finding items inside: G: This will be easy. However, shape of the foam is important.

FRUIT, FRESH OR FROZEN: see Vegetables.

TCE, finding drugs: E: ice has a dielectric constant of 9 while drugs are 2 to 3. The contrast is good.

ICE CREAM, finding drugs, contraband: E: ice cream has E' = 9. Drugs are E' = 2. This is good contrast. In addition, the ice cream is in a known, fixed volume.

METAL: N: microwaves will not penetrate metal.

PLASTIC: G: microwaves will penetrate plastic.

SHRIMP, FROZEN OR FRESH, see Fish.

SWALLOWERS, finding drugs swallowed by people: a good potential application which has been demonstrated by testing and analysis.

TRUCKS: M: an experienced operator can find items hidden in false panels such as the floors in flatbed trucks, or the walls in trailer.

VEGETABLES, FRESH, boxes, finding drugs: M: this is difficult for the most part since the box is not homogeneous. In some cases where the vegetables are small and uniform, or flat and leafy this could help an experienced operator.

VEGETABLES, FRESH, individual: E: Customs has found many fruits and vegetables hollowed out and filled with drugs. The normal response of an individual fruit or vegetable will be very strong since they are like water and have **E'** = 80, with drugs having E' = 2. The response is so different this can be done without referring to a standard.

VEGETABLES, FROZEN, boxes, finding drugs: G: Good contrast of frozen vegetables E' = 9 to drugs E' = 2. The volume is known and: fixed, and the vegetables are homogeneous in the volume.

WALLS OF CONCRETE, BRICK, CINDER BLOCK, finding metal, drugs, voids, water; see concrete.

WALLS OF WOOD: M: an experienced operator can find hidden items with advanced sensitivity settings. Knowledge of the construction of the wall is helpful.

WIRE: E: Thin wires act like an antenna and radiate back a strong signal. Wires as small as 40 gauge have been tested and easily found.

WOOD: G: Wood has a dielectric constant of E' = 5. A void in wooc will have a lower dielectric and will be detectable. The results will be enhanced with advanced sensitivity settings.

Note 1: In all testing it is easiest to make comparison readings to a known (unaltered) target. Standard readings can be established and used from test to test by recording them in a table.
Note 2: Volume important since the same material in two different volumes may read differently.
Note 3: Microwaves will detect metal very well since they reflect off the metal. Microwaves will not penetrate metal containers.
Note 4: Water absorbs microwave energy better than almost any non-metal material. (This is why microwave ovens cook so well). If

water **is** altered in any way, the alteration will be detected. This is why the bottle contents checking works so well.

Note 5: Dielectric Constant = ε'.

SPATIAL DYNAMICS APPLICATIONS,
42 WASHINGTON DRIVE
ACTON, MASS 01720

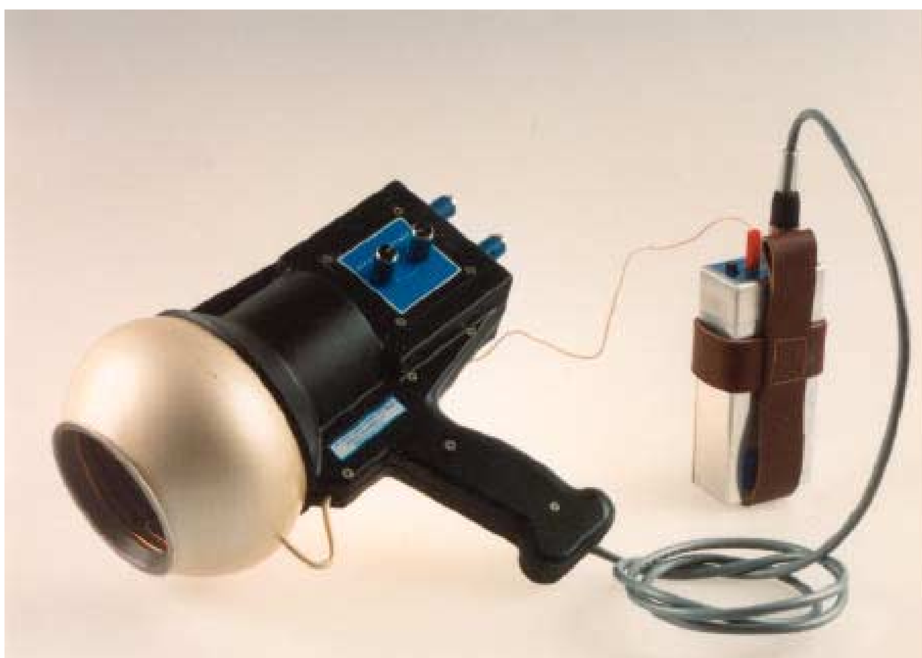
PHONE: 508 263 7704

APPENDIX

1) FIND DRUGS AND CONTRABAND information sheet published by Spatial Dynamics Applications, Inc., MA.

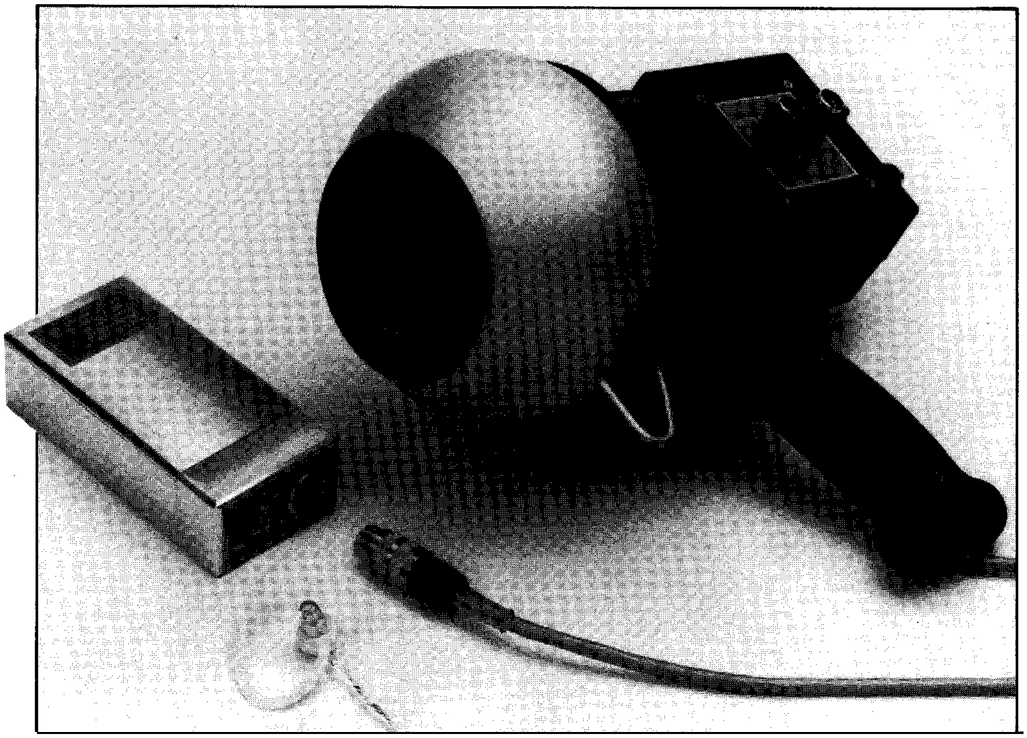
2) photographs of the M600P

PHOTOGRAPH 1 - The M600P being used on a bottle containing a liquid



PHOTOGRAPH 2 - The M600P with battery pack

Find Drugs and Contraband



The M600P is:

- Penetrating
- Portable
- Handheld
- Microwave
- Safe
- Easy to Use

☐ Finds Drugs, Explosives, Weapons
☐ Sensitive Microwave Energy
☐ Finds Anomalies in Most Materials
☐ Search From One Side
☐ Completely Safe (No X-Ray or Nuclear Radiation)

Finds Drugs, Contraband, Explosives Hidden in:

- Sealed Wine Bottles
- Any Glass Containers
- Cement Blocks
- Asphalt
- Blocks of Ice
- Frozen Shrimp or Fish
- Boxes of Flowers
- Bales of Cotton
- Bales of Clothing
- Wood (false compartments)
- Walls, Floors
- Commercial Goods
- Cardboard Boxes
- Fruit or Vegetables (Yams, Melons, etc.)
- Rolls of PVC
- Rolls of Textiles
- False Metal Compartments in Gas Tanks (Some Applications)
- False Compartments in Fiberglass Boats
- Tires of Cars or Trucks
- Sides of Suitcase
- Metal Cans (Some Applications)
- Metal 55 Gallon Drums (Some Applications)

M600P
Portable Drug and Contraband Detector

Typical Operation

The **M600P** is held in the hand and the opening placed against the material to be measured. The unit is turned on, producing a very Low-Level microwave signal that is absorbed in the test material and also reflected back into the **M600P.** The **M600P** compares the signal it produces with the reflected signal. The results are displayed on a meter on the rear panel of the **M600P.**

Technical Description

The **M600P** Portable Dielectric Tester utilizes patented nearfield microwave technology to measure the dielectric properties of materials. This technology has made possible a very compact and easy to use instrument.

For materials which are the same throughout (homogeneous), a change in reading will indicate something is in there which should not be. This will give a reason to look into something or to let it pass.

The depth of penetration for the **M600P** is about 4 ft. in air and is correspondingly less depending on the dielectric properties of the materials being tested. For example, for a bale of wool the depth is about 30" and for a water slurry 6".

Typical Search Scenarios:

1. In a shipment of asphalt or cement blocks, all will normally look the same. Hidden items will show up as differences from normal readings. Readings are taken from the same points from block to block.

2. Frozen shrimp or fish blocks with items frozen in the center will give different readings from normal. Readings are taken from one or two points in the center of the block.

3. Sealed bottles of wine, whiskey, or any drinkable fluid can be tested without opening. Water based fluids (drinkable), give a markedly different response than explosives or drugs. Readings can be taken through carry on bags.

4. In a shipment of similar boxes of ceramic fixtures or other commercial items, boxes can be screened to find those which are different from normal. This can be done from outside the unopened box.

5. Tires should be uniformly empty. A tire with drugs in it will show changes from normal.

Many other search scenarios have been tried with success. Consult our security professionals.

Advanced Search Scenarios

A user can collect data about the known response of a particular product, and use that from search to search. For example, wine bottles of a known size will always read similarly. A sharply different reading in a new carry on bag would indicate a different substance. In the same way, asphalt blocks will always give the same response. A change should trigger a closer look.

Specifications

· **Operating Frequency**	**600** Mhz
· **Operating Wavelength**	**50** cm. (19.7")
· **Measured Parameter**	Coefficient of Reflection
· **Output Device**	Digital meter (analog optional)
· **Output Power**	Less than 1 microwatt/sq. cm. @5cm.
· **Accuracy**	Better than 0.1%
· **Sensitivity**	Detects changes less than 0.05%
· **Response Time**	Less than 2.5 millisec
· **Safety**	Output power less than 1/5000 of FDA safety level
· **Primary Power**	9V battery pack; 120 VAC supply
· **Weight**	**4** lbs.
· **Instrument Case**	Included.

Applications Assistance

Call Us!!! We can help solve your application problem.

Other Products Available from SDA

M600L Laboratory Dielectric Tester: The **M600L** is designed to operate on a laboratory bench. It operates at the same frequency (600MHz) and has additional features that include:

- AM -Amplitude Modulated signal output
- PM – Phase Modulated signal output
- Switch -To display either AM or PM on the meter.
- Recorder
- Power Supply

M1800 Laboratory Dielectric Tester:
The **M1800** is similar to the M600 but has a higher operating frequency for better resolution vs. less depth of penetration.

SPATIAL DYNAMICS APPLICATIONS, INC.

42 Washington Drive, Acton, MA 01720
Phone (508) 263-7704 Fax (508) 263-7834