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Millimeter Attenuation and Reflection Coefficient Measurement System

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Millimeter Attenuation and Reflection Coefficient Measurement System

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MILLIMETER ATTENUATION AND REFLECTION COEFFICIENT MEASUREMENT SYSTEM

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Abstract

This paper presents the details to implement a WR15 attenuation and reflection coefficient magnitude measurement system. A discussion of precision and of systematic error is given along with equations for estimating limits of the error. Machine drawings are provided to fabricate the waveguide standards and necessary hardware not commercially available.

Key words: Attenuation; Measurement system; Millimeter; Reflection coefficient, VSWR.

1. Introduction

In the Electromagnetics Division of the National Bureau of Standards, Boulder, Colorado, work is proceeding toward the establishment and extension of calibration services at frequencies in the millimeter region. Among the work completed at this time is a system for the measurement of attenuation and reflection coefficient magnitude on waveguide devices in WR15 waveguide. The purpose of this report is to describe this calibration system and include the instrumentation, measurement procedure, and error analysis employed in the system development and evaluation.

2. System Description and Measurement Procedures

The system can be conveniently broken into two parts for the purposes of description and discussion. The part (subsystem) dealing with measurement of reflection coefficient will be described first.

2.1 Magnitude of Reflection Coefficient[1]

Immense improvements in reflectometer techniques over the past few years have made this method most accurate for the measurement of microwave and millimeter impedance (VSWR and reflection coefficient)[2] [1,2][3]. In particular, the

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[1] The reflection coefficient Γ at a single frequency, and for a single mode of propagation having a sinusoidal time variation, is the ratio of the incident to reflected wave amplitudes at a given terminal plane in a uniform waveguide. The reflection coefficient is a complex number having both a modulus (magnitude) and argument (phase).

[2] The voltage standing-wave ratio (VSWR), in terms of the above-defined reflection coefficient, is given by the relation,

$$\text{VSWR} = \sigma = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

The converse relation (i.e., $|\Gamma|$ in terms of σ) is

$$|\Gamma| = \frac{\sigma - 1}{\sigma + 1}.$$

A more complete discussion of reflection coefficient and VSWR is given by Beatty [2].

Note: The symbol σ is widely used to denote conductivity, but is used in this note only to designate VSWR.

[3] Figures in brackets indicate the literature references at the end of this paper.

tuned modified reflectometer, a single directional coupler with associated waveguide tuners, offers the best performance and accuracy over a large dynamic range. Untuned reflectometer techniques [3] have also been developed which provide a reasonable accuracy.

2.1.1 Subsystem Description

Figure 1 is a block diagram of the reflection coefficient magnitude calibration subsystem presently in use at NBS. The measurement system incorporates two microwave oscillators, the master oscillator (MO) and the sawtooth-modulated local oscillator (LO). The MO is tuned to the calibration frequency and controlled with an AFC circuit. The LO center frequency is tuned to either 30 MHz above or 30 MHz below the MO frequency.

MO energy is propagated to the reflectometer where it is reflected from the item under test and is applied to a mixer. LO energy is also coupled directly to this mixer to produce an i-f response of 30 MHz. The i-f response is then transmitted through a monitor network, which also provides a ground return for the mixer diode, and into a 30 MHz waveguide below-cutoff (WBCO) piston attenuator. Next, the attenuator output is amplified, detected, and filtered. The filtered voltage is then applied to a monitor scope and a strip chart recorder. For a dynamic range greater than 40 dB, the sawtooth audio modulation is amplified following the i-f amplifier and synchronously detected.

Figures 2, 3, are more detailed diagrams of the system.

In order to provide a coherent scope response, system stability, and wide dynamic range, a sawtooth voltage is superimposed upon the LO repeller voltage to frequency modulate (± 2 MHz) the LO. If better system stability than the modulated method provides is required, the LO can be controlled by an AFC circuit to maintain the i-f center frequency at a fixed 30 MHz. This can be accomplished by employing a separate AFC loop such as shown in figure 3. For more detail on system stability see section 3.3.2.

2.1.2 Measurement Procedure

The measurement is performed by: 1) attaching the unknown test item, Γ_u, to the reflectometer, 2) adjusting the gain of the amplifier to obtain a convenient reference response on a recorder (meter), 3) replacing the test item by a reflection coefficient standard ($|\Gamma_s| \simeq 1$), and 4) adjusting the 30 MHz standard attenuator to obtain the original output on the recorder. The reflection coefficient magnitude can then be calculated by using the formula,

$$L_R = 20 \log_{10} \frac{|\Gamma_s|}{|\Gamma_u|}, \tag{1}$$

where L_R is the measured relative return loss (the attenuation difference between $|\Gamma_s|$ and $|\Gamma_u|$). Tables are available to facilitate the calculation of $|\Gamma_u|$ [4]. Alternately, $|\Gamma_u|$ can be calculated from the equations,

$$L_R = -20 \log_{10} |\Gamma| \tag{2}$$

and

$$|\Gamma_u| = |\Gamma_s| \cdot |\Gamma|. \tag{3}$$

When measuring terminations having a sliding load (fig. 4) as a terminating element, both the maximum and minimum reflection coefficients are measured. Usually the reflection coefficient of the termination is taken as the average of these measurements.

Terminations having a small reflection coefficient ($|\Gamma| \leq 0.01$) and a sliding load $|\Gamma_L|$ as a terminating element are difficult to measure. Since both reflections are small, it is not possible to immediately identify whether the average reflection coefficient $|\Gamma|_{ave}$ belongs to the sliding load or to a discontinuity (fig. 4) associated with the termination. (For the case ($|\Gamma| > 0.01$), $|\Gamma|_{ave}$ is equal to the reflection coefficient of the discontinuity $|\Gamma_D|$ (to an order of $|\Gamma_L|^2$) provided that $|\Gamma_D| > |\Gamma_L|$). This is because the average value of reflection coefficient is associated with that element which has the largest reflection (see Appendix A).

The usual method to separate the two reflection coefficients is to insert a low-loss discontinuity either inside the termination or attached to the waveguide flange of the termination in order to provide a reflection which is large compared to that of the sliding load. A flat metal plate with dimensions smaller than nominal waveguide dimensions and which has a VSWR $\simeq$ 1.2 can easily be attached to the termination and also provide the necessary discontinuity. An alternate method is to use two different sliding loads inside the termination if it is physically practical.

The measurement procedure is to attach the plate to the termination, measure the maximum and minimum reflection coefficients as a function of the sliding load, and calculate the respective VSWR's, ${}^{d}\sigma_{max}$ and ${}^{d}\sigma_{min}$. (The d superscript is used here to denote the VSWRs measured with the discontinuity (plate) attached.)

The VSWR of the load σ_L is calculated from the equation [5]

$$\sigma_L = \sqrt{{}^{d}\sigma_{max}/{}^{d}\sigma_{min}}. \quad (4)$$

Next, measurements of the maximum and minimum reflection coefficients are made with the discontinuity (plate) removed, and the maximum and minimum VSWRs (σ_{max} and σ_{min}) are calculated. Here, σ_{max} and σ_{min} are not to be confused with the VSWRs in eq. 4 but pertain only to the VSWRs with the discontinuity (plate) removed. Substitution of σ_{max} and σ_{min} into the equations,

$$\sigma_1 = \sqrt{\sigma_{max}/\sigma_{min}}, \quad (5)$$

and

$$\sigma_2 = \sqrt{\sigma_{max}\ \sigma_{min}}, \tag{6}$$

yields the VSWRs of the termination discontinuity and the sliding load where σ_1 and σ_2 are the VSWRs of the elements with the smallest and largest reflection, respectively. Comparison of eq. 5 and eq. 6 with eq. 4 removes the ambiguity as to which VSWR is associated with the sliding load and which VSWR is associated with the termination discontinuity.

When measuring terminations or nominally nonreflecting one-ports[4] which have a return loss greater than the dynamic range of the measurement system, other measurement procedures must be used. Four suitable techniques are described below. The last two methods to be described (rf and i-f substitution) can be also implemented for measuring attenuators over an extended attenuation range. Details on direct substitution attenuation measurements are given in reference [6]. All methods assume that adequate signal power is available.

The first method is to measure the return loss in two steps, first calibrating the reflection coefficient of a transfer standard having a return loss of about 32 dB ($|\Gamma| = 0.025$) by the method described previously. Then, with the power level at the measurement port increased to compensate

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[4] A nominally nonreflecting one-port is a termination which is intended to produce no reflection or nearly no reflection ($|\Gamma| \leq 0.001$).

for the return loss of the transfer standard (32 dB), the unknown $|\Gamma_u|$ is compared to the transfer standard. $|\Gamma_u|$ is calculated from eq. 1 where $|\Gamma_s|$ is the reflection coefficient magnitude of the transfer standard. Alternately, the return loss of the transfer standard can be added to the measured return loss to obtain the return loss of the unknown.

The second method utilizes a reflection coefficient standard that is fairly close in magnitude to the unknown termination. In this case only a relatively small return loss measurement which is within the dynamic range of the system need be measured. Some excellent possibilities of reflection coefficient standards of low VSWR are discussed in section 4.1.

The third method utilizes a calibrated rf attenuator isolated from and located between the generator and reflectometer. This method makes a direct comparison between the standard of reflection coefficient ($|\Gamma_s| \simeq 1$) and the unknown. When the unknown is compared to the standard, a portion of the substituted return loss is placed in the rf attenuator and a portion in the i-f 30 MHz standard attenuator and the losses summed. The unknown is calculated from eq. (1).

Since the rf attenuation in the third method is not always accurately known, the fourth procedure makes use of the i-f attenuator to determine the attenuation in the rf attenuator. To do this the i-f attenuation is transferred to a second auxiliary rf attenuator. Next, the attenuation in the original (third method) rf attenuator is measured with the i-f attenuator. The sum of the two i-f attenuator losses is then used in eq. (1) to calculate $|\Gamma_u|$. Although this method is tedious, it has been found by experience to be more accurate than the third method.

2.1.3 Brief Modified Reflectometer Theory and Tuning Procedure

For the measurement procedures outlined previously to be valid, the output response from the modified reflectometer must be proportional to the reflection coefficient of the device located at the measurement plane. In order to obtain this output response, the imperfections in the directional-coupler-tuner assembly and the reflections from the equivalent generator are eliminated or minimized by appropriate tuning adjustments as will be described.

When a signal originating from the generator is incident on a device presenting a reflection coefficient, Γ_L, at terminal surface T_2 (fig. 5) in a reflectometer, a portion of the reflected signal is coupled to the output arm of the coupler. The output response b_3 can be expressed by the equation [1],

$$b_3 = c' \frac{\frac{1}{K} + \Gamma_L}{1 - \Gamma_{2i}\Gamma_L}, \qquad (7)$$

where Γ_{2i} is the reflection coefficient of the equivalent source impedance looking back from T_2 and

$$|K| \simeq |S_{21}| \, 10^{D/20} \tag{8}$$

D is the directivity of the reflectometer and the transmission coefficient, S_{21}, is defined as the ratio of the wave amplitude at T_2 to that at T_1 when T_2 is terminated by a nonreflecting device. S_{21} has magnitude values of approximately 0.707, 0.95, and 0.995 for a 3 dB, 10 dB, and 20 dB coupler, respectively. Thus, when employing a coupler with a directivity of 40 dB, $\frac{1}{|K|}$ is approximately 0.01 to 0.014 (3-20 dB coupler). These values of $\frac{1}{|K|}$ can be equal to or larger than $|\Gamma_L|$ so that from eq. (7) it can be seen that considerable error could result if the assumption were made that b_3 was proportional to Γ_L. In the denominator of eq. (7), the magnitude of $\Gamma_{2i}\Gamma_L$ is relatively small but still gives an appreciable error which will be discussed later.

Since both the directivity and Γ_{2i} errors are significant in the detected reading of the reflectometer, it is necessary to reduce their effects by appropriate tuning operations which are to raise the directivity of the reflectometer and to reduce Γ_{2i} to a negligible value. Reduction of Γ_{2i} to zero implies the elimination of multiple reflections at terminal plane, T_2. If one could make the directivity infinite and

$\Gamma_{2i} = 0$, eq. (7) would become

$$b_3 = c'\Gamma_L \tag{9}$$

In other words, the output would be directly proportional to the reflection coefficient of the device connected to T_2, and the ratio of the $|b_3|$ response from the device to the response from a standard of reflection coefficient would give the proper value of Γ_L (see eq. (1)). Although in principle these conditions are realizable, in practice it is possible only to approach them. However, one can approach them so nearly that only a small residual error remains. This deviation from perfect tuning conditions causes what is called the tuning error. The section on measurement errors gives the formulas to calculate the limits of tuning error. For a more detailed discussion of tuning theory see [1,2].

Various techniques can be employed in raising the directivity of the reflectometer and reducing Γ_{2i} to a negligible value. The individual techniques which are preferred by most metrologists are reviewed here.

The directivity of the reflectometer is raised by inserting a sliding load of small reflection coefficient (VSWR of 1.01 to 1.001) into the uniform precision waveguide (fig. 5) and adjusting tuner A for a null response at the detector. (It is possible to obtain a false tuning adjustment if the null is not obtained first). Next, while the sliding load is moved (at least a half wavelength) to obtain the maximum-minimum variations, tuner A is adjusted to make these variations as small as possible. Usually a variation of 0.5 to 1 dB is considered satisfactory.

After making the directivity adjustment, a sliding short circuit is substituted for the sliding load in the precision waveguide to make the Γ_{2i} adjustment. Tuner B is adjusted to minimize variations in $|b_3|$ in the same manner as tuner A except that a detector null is not obtained originally. The adjustment is usually continued until the Γ_{2i} variation is less than 0.005 dB. An automated carriage has been devised to facilitate the tuning procedures [7] and its use or a similar device is highly recommended for tuning at millimeter frequencies.

It is always necessary to repeat the directivity adjustment (tuner A), after adjusting tuner B, but the Γ_{2i} adjustment (tuner B) usually need not be repeated again if the output variation is reduced to 0.002 dB or less originally. These adjustments should provide the necessary conditions that the output signal is proportional to the reflection coefficient of the device at T_2, so that the measurement methods outlined can be used.

Machine drawings for fabricating the tuners, sliding load, and sliding short are given in Appendices D, E, and F respectively.

2.2 Attenuation[5]

The i-f substitution technique is most widely accepted as the most accurate and most versatile method of performing attenuation measurements over a wide range of frequencies. Several system configurations are possible with this measurement technique [6]. The most commonly used is the series i-f substitution system shown in figure 6 and described below.

2.2.1 Subsystem Description

The basic series i-f substitution system for measurement of attenuation incorporates the hardware of the reflection coefficient subsystem; the insertion point for attenuators being located at the terminal plane for reflection coefficient measurements. The reflectometer provides a "matched generator" and is also used to tune the receiver port so that there are no multiple reflections between the input and output ports of the device-under-test and the system into which it is inserted.

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[5] Attenuation is a general transmission term used to denote a decrease of signal magnitude, usually resulting from either a dissipative or reflective loss. In this note, the term attenuation also implies a non-reflecting system at the place where the attenuator is inserted.

A signal from the MO is propagated through the reflectometer and device-under-test (insertion point) and frequency converted (heterodyned) to 30 MHz by mixing with the LO. After the 30 MHz signal is attenuated by the WBCO standard attenuator, it is amplified, detected and displayed on a monitor scope and chart recorder.

With this system configuration a change in attenuation (e.g., an increase) in the device-under-test requires a corresponding change (decrease) in the WBCO attenuator. Thus, this configuration is called a series i-f substitution system.

2.2.2 Measurement Procedure

Preparatory to making a measurement the reflectometer in the RF source portion of the waveguide system is tuned by the procedures outlined in section 2.1.3 in order to present a matched generator to the test device. The RF detector section (fig. 7) contains a precision waveguide and a waveguide tuner which is the output port of the insertion point. After the reflectometer is properly tuned, the insertion point is closed and aligned. The waveguide tuner in the RF detector section is then adjusted for a reflectometer null response (i.e., no i-f detector response). This completes the tuning adjustments necessary to present the device-under-test with a matched insertion point.

The measurement is performed by: 1) inserting the device under test into the system at the insertion point, 2) adjusting the gain of the i-f amplifier to obtain a convenient detected reference response on a recorder (meter) (Note: when measuring variable attenuators, the gain is adjusted with the rf attenuation inserted), 3) removing the rf attenuation, and 4) substituting i-f attenuation from the WBCO standard to restore the detected response to the reference value to obtain a direct measure of the rf attenuation.

When setting either the standard or a rotary vane attenuator, the dial should always be turned in the direction of increasing attenuation to avoid backlash effects from the gear mechanisms.

Alternate methods for making attenuation measurements when the dynamic range of the detector system is exceeded are described in section 2.1.2.

It should be noted that alignment of the flanges between the device-under-test and the insertion point should be as exact as possible in order to obtain repeatable measurements.

3. Systematic Measurement Errors

The discussion of the limits of systematic measurement errors encountered is divided into three parts. The first part deals with errors in the measurement of reflection coefficient. The second part deals with errors due to mismatch in measuring the attenuation. And the third part deals with errors common to the measurement of both attenuation and reflection coefficient. Estimated systematic error limits for NBS WR15 components and systems are summarized in appendices B and C.

3.1 Reflectometer Errors

3.1.1 Tuning Errors

Evaluation of the tuning errors in a tuned reflectometer is very important. Since the ideal conditions of $K = \infty$ and $\Gamma_{2i} = 0$ will not be realized in practice, the relation $b_3 = c'\Gamma_L$ will not be exact, and a residual error is present in the measurement.

The maximum relative error in an unknown test item, $|\Gamma_u|$, due to $K \neq \infty$ and $\Gamma_{2i} = 0$ is given by the equation,[6]

$$\frac{|d\Gamma_u|}{|\Gamma_u|} \leq \frac{1}{|K|} \frac{|\Gamma_S| + |\Gamma_u|}{|\Gamma_u \Gamma_s| - \left|\frac{\Gamma_u}{K}\right|} \tag{10}$$

where $|K|$ is approximated by eq. 8 and $|\Gamma_s|$ is the reflection coefficient magnitude of the standard.

To obtain the approximate magnitude of K, a load of small known reflection coefficient, Γ_L, is placed in the precision waveguide section and its phase is varied by sliding it more than one-half wavelength. Next, the attenuation difference, R, in decibels between maximum and minimum output

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[6] Equation (10) contains a typographical error in reference [2].

signal variation is noted. This is the variation observed when raising the directivity of the reflectometer (section 2.1.3). Then, $|K|$ is calculated from the equation,

$$|K| = \frac{10^{R/20} + 1}{(10^{R/20} - 1)|\Gamma_L|}. \tag{11}$$

The estimation of $1/|K|$ is facilitated by figure 8.

A typical value that can be obtained when sliding a load ($|\Gamma_L| = 0.001$) is $R = 0.5$ dB so that $|K| \simeq 3.5 \times 10^4$. This corresponds to raising the directivity of the reflectometer to greater than 90 dB. At millimeter wave frequencies 80 dB is usually the upper directivity limit that can be maintained for a three to four hour time interval without readjustment, while 90 dB can be maintained over the same interval for microwave frequencies.

The maximum relative error due to $\Gamma_{2i} \neq 0$ but $K = \infty$ is given by the relation,[7]

$$\frac{|d\Gamma_u|}{|\Gamma_u|} \leq \frac{(|\Gamma_u| + |\Gamma_s|)|\Gamma_{2i}|}{1 - |\Gamma_{2i}\ \Gamma_u|}, \tag{12}$$

where $|\Gamma_{2i}|$ is obtained from the equation,

$$|\Gamma_{2i}| = \frac{10^{R/20} - 1}{(10^{R/20} + 1)|\Gamma_L|} \tag{13}$$

in which R is now the output dB variation observed when a short circuit ($|\Gamma_L| \simeq 1$) is slid more than one-half wavelength. Typical values are $|\Gamma_L| = 0.996$, and $R = 0.003$ so that

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[7] Equation (12) contains a typographical error in reference [2].

$|\Gamma_{2i}| \simeq 0.0002$. The estimate of $|\Gamma_{2i}|$ is facilitated by figure 9.

The above results should not be difficult to obtain provided good tuners and reasonable system stability are available. As a word of caution, the tuning conditions are sharply frequency sensitive and cannot be accurately maintained unless the master oscillator is frequency controlled.

Equations (10), (11), (12), and a form of (13) were presented in reference [2].

3.1.2 Precision Section Error

Although the precision section of waveguide used in the reflectometer is carefully constructed and considered to be a standard transmission line, and thus could be discussed in the section on standards, it is also an integral part of the reflectometer. Thus, the errors associated with that waveguide section are presented here.

A major portion of the reflectometer error is caused by the cross-sectional deviation of the precision section from standard waveguide dimension. It should be noted that this particular error is the limiting factor in obtaining better accuracy in waveguide impedance measurements, because it is possible to reduce the tuning errors to a value much smaller than the precision section error. Although present fabrication techniques make possible a waveguide tolerance of ± 50 microinch, this error can be significant. The quoted limit of error from this source may be actually too conservative, and a future reduction may be possible if and when a more rigorous mathematical analysis of this type of problem can be performed.

The residual reflection coefficient magnitude caused by dimensional deviations Δa and Δb in the a and b dimensions respectively, is given by the formula,

$$\Delta\Gamma = 2\left(\left(\frac{\lambda_g}{\lambda_c}\right)^2 \frac{|\Delta a|}{4a} + \frac{\sigma}{(1+\sigma)^2}\frac{|\Delta b|}{b}\right), \qquad (14)$$

where

a = the broad waveguide dimension,

b = the narrow waveguide dimension,

λ_g = the guide wavelength,

λ_c = the cutoff wavelength,

o = the measured VSWR of the item under test. (Not to be confused with conductivity of the metal).

This formula considers only the change in characteristic impedance of the waveguide. Also, the respective error terms are derived while holding the other waveguide dimension constant at the nominal dimension. The "a" dimension error term is believed correct to 2 percent. The "b" dimension is correct to 1 percent for VSWR's less than or equal to 1.1 and varies to 10% for VSWR's of 2. Graphs of the respective errors for WR15 waveguide are given in figure 10 and figure 11.

Another possible error is due to the fact that the inside corners of the waveguide are filleted and not sharp.

The reflection from the junction of standard rectangular waveguide to filleted waveguide has been derived [8] and is given by the expression,

$$\Delta\Gamma = \left(\frac{\lambda_g R}{a}\right)^2 \cdot \frac{4 - \pi}{8ab} \tag{15}$$

where R is the radius of curvature of a filleted corner and the other parameters are as given for the previous equation.

Machine drawings for fabricating brass and invar precision waveguide sections are given in Appendix G.

3.2 Attenuation Error

3.2.1 Mismatch Errors

The error due to mismatch must be considered in making attenuation measurements because the attenuator is not always inserted in a perfectly matched system.

The attenuation difference of a variable or rotary-vane attenuator is measured by moving the vane from a zero or reference angular position to the desired vane angle or attenuation. The mismatch error [9] is expressed for the attenuation difference measurement by the equation,

$$\varepsilon(\mathrm{dB}) = 20 \log_{10} \frac{\left|(1 - {}^{(f)}\Gamma_i\Gamma_g)(1 - {}^{(f)}S_{22}\Gamma_L)\right|}{\left|(1 - {}^{(i)}\Gamma_i\Gamma_g)(1 - {}^{(f)}S_{22}\Gamma_L)\right|} \tag{16}$$

where the frontscripts (i) and (f), refer to the initial and final values, respectively, and Γ_i is the input voltage reflection coefficient of the variable attenuator when the attenuator is terminated with a load (receiver) of reflection coefficient, Γ_L. Γ_g is the reflection coefficient of the generator, and S_{22} is the reflection coefficient at the output port when the input port is terminated with a load $|\Gamma_L| = 0$.

For insertion loss measurement of a fixed attenuator the mismatch error [6] is given by the equation,

$$\varepsilon(\mathrm{dB}) = 20 \log_{10} \frac{|(1 - S_{11}\Gamma_g)(1 - S_{22}\Gamma_L) - S_{12}S_{21}\Gamma_L\Gamma_g|}{|1 - \Gamma_g\Gamma_L|}, \qquad (17)$$

where S_{11} is the attenuator input reflection coefficient, and S_{12} and S_{21} are the attenuator transmission coefficients. Figure 12 can be used to quickly estimate the mismatch error for fixed attenuators having attenuation of 20 dB or more. A typical value of mismatch error is approximately 0.008 dB for WR15 attenuators (fixed or variable) with a system VSWR of 1.02 at the insertion point. The magnitude of this error is approximately 50 percent of the total systematic error for attenuation measurements from zero to 30 dB, and approximately 20 percent for a 50 dB measurement (see also Appendix 3).

3.3 System Measurement Errors -- Attenuation and/or Reflection Coefficient Magnitude

3.3.1 Converter Linearity

A knowledge of the degree of linearity of the power conversion of the mixer is essential in the i-f measurement system. When using a diode mixer in heterodyne receivers, nonlinearity is always present. This nonlinearity is a function of the ratio of the local oscillator power to the master oscillator power. Empirically, it has been shown in the NBS WR15 waveguide system that a 27 dB ratio (i.e., the MO power 27 dB down from the LO power) will give a nonlinearity less than 0.003 dB over the measurement range of 0-50 dB when the LO power is set at 2-3 mW at the mixer. The deviation from linearity is reduced when the signal power in the mixer is decreased relative to the local oscillator power. These results are in good agreement with the theory [10] (see figure 13).

In practice, the degree of linearity is established by measuring the same known attenuation step (e.g., 5 or 10 dB) at various power levels over the required measurement range. The difference between the measured value at the higher level and the value of attenuation at low levels, ΔdB (decibel), is the converter nonlinearity.

The relative error in reflection coefficient magnitude due to nonlinearity is calculated from the formula,

$$\frac{|\Delta\Gamma|}{|\Gamma|} = 0.115\ \Delta\mathrm{dB} \tag{18}$$

where ΔdB (decibel) is the deviation from linearity. The error for an attenuation measurement is ΔdB.

3.3.2 System Instability

Instability errors caused by power or frequency fluctuations are dependent on the particular generators, amplifier, detectors, power supply, and frequency stabilizer used and cannot be predicted in advance for a particular system. The variation of the output signal from an average power level can be held to less than ± 0.1 dB with a stable power supply and water cooling of the rf source (klystron). Phase locking the signal klystron to a stable source operating at a lower frequency (fig. 3) can hold the i-f output level fluctuations to approximately ± 0.005 dB for a 30-60 second interval. The two-loop AFC used here accomplishes this stability with only a water-cooled LO. When the two-loop AFC was applied to the LO also, the stability was held to better than ± 0.002 dB for a 1-2 minute interval. Frequency stability of this system (WR15) is approximately 1-2 kHz short-term and 5-10 kHz daily drift.

Instability errors are usually treated as random errors of measurement, a value being assigned after several hundred random measurements are made. When only a few measurement data are available, the error is formulated from eq. (18).

Connect-disconnect instabilities and repeatabilities of flanges, attenuators, and terminations are discussed in Section 5.1 and 5.2.

3.3.3 Leakage

3.3.3.1 RF Leakage

The effect of rf leakage becomes noticeable and increases the measurement error when measuring an attenuation ratio of 35-40 dB or more. This applies to a typical system where no special precaution has been made to control the leakage. The maximum attenuation error can be computed from the equation [11],

$$\Delta dB = 20 \log_{10} \left(1 \pm \sqrt{\frac{P_L}{P_S}} \right) \qquad (19)$$

where P_S and P_L represent the signal power and leakage power, respectively. The reflection coefficient error is given by applying the results of eq. (19) to eq. (18).

In practice eq. (19) is not easily utilized, because an accurate measure of the leakage power cannot be made, but it can be applied to yield approximate error limits. A suggested method is to use a RF receiver (e.g., the attenuation

LO receiver) with an incorporated dial readout attenuator attached. This receiver is mobile enough to be placed near possible sources of leakage and can give an indication of the leakage signal. The receiver can be "calibrated" by the usual attenuation measurement system.

The leakage can be eliminated or minimized by several trial-and-error techniques. Placing the signal sources in shielded containers will usually sufficiently reduce this leakage source. Waveguide joints can be wrapped with steel wool or metal foil, and polytetrafluoroethylene-metal gaskets [12] have been used at microwave frequencies. Also, if the system is of a permanent nature, painting joints with a solution containing a high silver content will eliminate the leakage. Unfortunately, a major source of leakage may be the test item (e.g., a rotary vane attenuator). In the case of some commercial attenuators, the leakage power is down only 40 dB from the incident power in the waveguide and it is rarely down more than 60 dB. Fabrication techniques for NBS rotary-vane attenuators using absorbing material have been devised to reduce the leakage to more than 120 dB below the incident power [13]. Leakage in an NBS fabricated WR15 rotary-vane attenuator was shown to be at least 80 dB below the incident power.

3.3.3.2 Intermediate Frequency Leakage

I-f leakage is present around the standard attenuator, i-f amplifier, converter, and the associated i-f coaxial cables. The leakage from the standard attenuator can be contained by proper fabrication techniques. The i-f amplifier should be placed in a shielded container which has filtered power input connectors. The coaxial cable connector leakage can be reduced by wrapping the joint with lossy cloth and metal foil, but the suggested procedure is to use a conductive silver paint on threaded connectors and pack metal foil around the outer walls of BNC type connectors.

A field strength meter and probe or alternately an additional i-f receiver can be used to detect this type of leakage.

If the i-f leakage cannot be controlled adequately (30-50 dB range), a rf substitution in conjuction with the i-f substitution (similar to the method used for nonreflecting terminations (see Section 2.1.2)) will usually overcome the problem, since the signal power will be much larger than the leakage power. Although this method requires an additional calibration, it may yield a more accurate attenuation measurement. The technique is to remove approximately 20-25 dB of attenuation from the attenuator which holds the MO-LO 30 dB ratio (for power linearity) to an auxiliary attenuator. The unknown item is then calibrated by using the attenuations of the rf and i-f attenuators.

At least 20-25 dB (the amount removed previously) must be measured by the rf attenuator. If the i-f leakage cannot be reduced to a negligible amount, an estimate of its ΔdB attenuation change can be treated as a systematic error as in the case of rf leakage.

3.3.4 Signal-to-Noise Error

In the series i-f substitution system used at NBS, it has been demonstrated experimentally that attenuation measurement error due to noise is not significant. This is because the principal noise present in the 30 MHz detection system originates from the i-f amplifier and not the mixer. Thus, since the i-f amplifier receives a constant signal level from the 30 MHz attenuator, as is the case with the series i-f substitution, no apparent signal-to-noise error arises. The latter statement assumes a 50 dB range only. (There may be some range greater than 50 dB where the mixer noise dominates).

An error due to noise that may be significant is that due to loss of readout resolution (i.e., the true signal level is not readily determined from the random variations caused by noise). This problem can usually be corrected by using a long time-constant filter after the amplifier detector when measuring over a dynamic range of 0-50 dB. Also, the resolution can be improved by increasing the signal power and using the i-f and rf substitution technique described previously.

The measurement error from random variations due to a small signal-to-noise ratio is the observed readout variation in decibels for attenuation measurements, and the associated reflection coefficient error is given by eq. (18).

4. Standards

4.1 Reflection Coefficient Magnitude Standards

The standard of reflection coefficient used for impedance measurements at NBS is the quarter-wavelength short-circuited waveguide, more commonly called the quarter-wave short circuit (fig. 14).

The main advantages of this type of standard are: 1) the reflection coefficient magnitude can be calculated from derived formulas given in references [14], [15] if conductivity or attenuation measurements [16], [17] of the waveguide are available. Relatively crude measurements of conductivity will suffice to obtain the reflection coefficient to excellent accuracy (fig. 15). For example, a 20 percent error in the conductivity measurement will result in only a 0.015 percent error in the standard; 2) the axial component of current vanishes a quarter-wavelength from the shorting plate (fig. 16) which makes the dissipative loss in the waveguide joint negligible; and 3) small dimensional variations in the waveguide cross section have a negligible effect on the reflection coefficient. An increase in height of 0.001 inch causes 0.0008 percent change in reflection coefficient (fig. 17) at 62.5 GHz; an increase in width of 0.001 inch causes approximately a 0.001 percent change at the same frequency (fig. 18). NBS short circuits are fabricated from electroformed silver or copper to a tolerance of ± 0.0002 inch for the narrow and wide waveguide dimensions.

The critical dimension of a short circuit is the length (ideally a quarter wavelength). The length of the short circuit must be accurately dimensioned in the fabrication process in order to achieve the vanishing of the axial component of current at the connector surface. If the electrical length is different from that at the design frequency, current will flow across the discontinuity and result in a loss of power, so that the reflection coefficient will be less than the calculated value.

The proper length of the short circuit corrected for the change in phase factor due to guide attenuation [18] is given by the equations,

$$\ell = \frac{1}{(1 + \alpha_m/\beta)} \left(\frac{\lambda_g}{4} - \frac{\alpha_m}{\beta} \ell_{ep}\right) \qquad (20)$$

and

$$\ell_{ep} = \frac{b(\lambda/\lambda_g)^2}{[2(b/a)(\lambda/\lambda_c) + \varepsilon_r]} \qquad (21)$$

where:

α_m = the measured waveguide attenuation constant,

$\beta = \frac{2\pi}{\lambda_g}$ = the wave phase factor,

λ_g = the guide wavelength,

λ_c = cutoff wavelength,

λ = free space wavelength,

b = narrow inside dimension of waveguide,

a = broad inside dimension of waveguide,

and ε_r = relative dielectric constant of the laboratory environment.

The reflection coefficient magnitude ($|\Gamma_s|$) is given by the equation,

$$|\Gamma_s| = 1 - 2\alpha(\ell + \ell_{ep}). \tag{22}$$

The attenuation constant is obtained by comparing the change in attenuation between a quarter-wave short circuit and a five-quarter-wave short circuit which is designed to operate at mid-frequency (mid-frequency is not essential) of the particular waveguide band. The attenuation at other frequencies in the particular waveguide size is given by the equation,

$$\alpha = \alpha_m \left(\frac{f}{f_m}\right)^{3/2} \left(\frac{\varepsilon_r + 2(b/a)(\lambda/\lambda_c)^2}{\varepsilon_r + 2(b/a)(\lambda_m/\lambda_{cm})^2}\right) \left(\frac{\lambda_g}{\lambda_{gm}}\right)^2 \tag{23}$$

where the m-subscripted parameters correspond to the parameter wavelength values at the mid-frequency f_m.

The reflection coefficient magnitude measurement error due to the quarter-wave short circuit is directly related to the error of the standard. In other words,

$$\frac{|d\Gamma|}{|\Gamma|} = \frac{|d\Gamma_s|}{|\Gamma_s|}.$$

The fractional error in the reflection coefficient of the NBS quarter-wave short circuits is estimated to be less than ± 0.03 percent.

Machine drawings for fabricating quarter-wave short circuits are given in Appendix H.

The previous discussion on quarter-wave shorts does not mean to imply that other reflection coefficient standards could not be fabricated in WR15 waveguide. Examples of several possibilities are half-round inductive obstacles [18, 19], waveguide irises, inductive and capacitive posts [20, 21] and waveguide holes [22].

4.2 Standard Attenuator

The IF substitution method has been used at NBS for comparison of attenuation difference and insertion loss in waveguide sizes WR28 to WR430 for many years. This method employs a waveguide below-cutoff (WBCO) attenuator operating at the selected frequency of 30 MHz. The WBCO is a continuously variable attenuation standard whose incremental attenuation may be closely predicted from a knowledge of its waveguide dimensions [23]. If the waveguide section is uniform, nearly lossless, and excited sinusoidally in only one mode, the field decays exponentially along the waveguide in a predictable manner.

Thus, a probe or pickup coil which is moved a known distance (with respect to an excitation coil) along the waveguide axis causes a calculable change in insertion loss. If certain constraints are applied regarding frequency of operation, resistivity of the waveguide, and the waveguide dimensions, the attenuator will constitute a nearly ideal standard.

Grantham and Freeman have published detailed theoretical factors affecting the design of the WBCO attenuator and its use as a standard attenuator [24]. The NBS Monograph 97 [6] treats the WBCO for general considerations, dimensional tolerances and accuracy of measurement of displacement, skin depth corrections, loading effects, and mode purity.

The errors in the NBS WBCO attenuator is estimated to be within 0.002 dB + 0.002 dB/20 dB. The error in reflection coefficient magnitude is given by application of eq. (18).

The machine drawings required to reproduce the NBS model VII WBCO standard attenuator are included in Appendix I.

Figure 19 is a photo of an NBS WBCO attenuator.

4.3 Interlaboratory Standards

4.3.1 Reflection Coefficient

The most frequently encountered type of interlaboratory standard (fig. 20) uses a change in height of the narrow waveguide dimension to achieve a calculable reflection coefficient. The ratio of waveguide heights is closely equal to the VSWR for ratios less than 1.5. The frequency characteristic of this type of device is dependent on the capacitive effect of the waveguide discontinuity, but it is of second order. Formulas are available [20] for the capacitive correction terms. Thus, this type of standard has the desirable qualities of being more broadband than most types and having a calculable reflection coefficient. This type of device usually incorporates a low-reflection sliding load to terminate the structure.

Caution should be observed when selecting interlaboratory standards for measurement purposes. Two of the main sources of trouble in a poor quality standard are nonflatness of the connector (flange) surface (see fig. 4) and mechanical and electrical instability of the sliding load incorporated in the reflector.

A connector (flange) surface which has protrusions, bent surfaces or separated seams (where the device is fabricated from 2-4 separate pieces) does not mate properly so that there is excessive joint loss and leakage which will change with use of the standard, thereby changing the measured value. Another disadvantage of joint loss is the increased leakage signal which can effect the measurement accuracy. Also, protrusions on the connector (flange) surface can damage the fine surface finish of a precision waveguide section which will degrade the accuracy of the measurement system.

The electrical instability of the sliding load is the most common flaw in an otherwise good standard. It is possible to overcome this fault by improving the mechanical fit between the shaft and the shaft hole, or by providing a better sliding fit between the load supporting mechanism and the waveguide. The recommended procedure is to mount a pyramidal taper on a block which has teflon guides that provide a close fit with the waveguide walls. Both the taper and the block should be made from an rf absorbing material. If properly constructed, the electrical instability is virtually eliminated.

Other qualities to be considered in selection of a standard are: 1) accessibility to the reverse side of the connector (flange) surface to provide fast connect/disconnect, and 2) sturdy construction to eliminate flexing of the flange and associated waveguide.

Cautions to be observed before and after calibration are: 1) Inspect for flat front and reverse connector (flange) surfaces. This includes removal of paint and uneveness on the reverse side which can cause different pressures to be applied to the mating surface, 2) inspect interior waveguide walls for freedom from dust and lint, and 3) inspect connector surfaces for freedom from grease and corrosion.

4.3.2 Attenuation

There are two basic types of rf attenuation interlaboratory standards, the fixed attenuator [25] for insertion loss and the variable attenuator for attenuation difference.

There are two designs of variable attenuators that are suitable for calibration. One type has a resistive vane which moves into the waveguide field from a side wall. The other type is the rotary-vane attenuator. Both types of attenuators have good resolution at low values of attenuation, but the rotary-vane attenuator has superior resolution at high values as compared to the first type. The rotary-vane attenuator is less frequency-sensitive and has less incremental phase change than the other type.

The rotary-vane attenuator which basically consists of a dissipative vane rotated in a circular waveguide is the preferred variable attenuation interlaboratory standard. It has the property that the "ideal" attenuation can be calculated by the expression

$$A = -40 \log \cos \theta + c \qquad (25)$$

where θ is the angle between the rotating vane and the polarization of the circular TE_{11} mode, and c is the residual attenuation when $\theta = 0$.

Equation (25) is ideal because fabrication imperfections can cause deviations in actual attenuation for a known vane angle θ. Among the factors causing these deviations are mismatch, misalignment of the rotating vane, insufficient attenuation of the vane, imperfections in the gear drive mechanisms, readout parallax, and a warped vane. Vane alignment techniques have been developed to reduce the errors from stator and rotating vane misalignment [26, 27, 28]. Likewise, fabrication techniques have also been improved so that the mechanical and physical imperfections are minimized [13].

Two main types of single-value attenuators are the fixed pad and the single-step attenuator. The disadvantage of the fixed pad is that it must be inserted and removed during a calibration, thus requiring good system stability and a repeatable connect-disconnect system assembly (see Section 5.2 for measurement results).

The step attenuator can remain in the system during its operation and thus overcomes the disadvantage of the fixed pad if its mechanical characteristics are stable and repeatable. The step attenuators usually consist of a movable resistive vane located between the two sets of coupling holes of an in-line directional coupler. When the vane is located in the center of the waveguide, energy is transmitted through the device via the coupling path, thus being attenuated in proportion to the design coupling factor. When the vane is located in the minimum electric field (against the wall) only a small residual attenuation results. Thus, with this device a fixed attenuation step can be measured without insertion and removal of the device. Other advantages of this device are low VSWR and minor frequency sensitivity.

Precision calibrated attenuators used as interlaboratory standards require careful handling and should meet the following criteria to give satisfactory results. They should:

1) be electrically stable over several years time,
2) be mechanically rugged so that the electrical characteristics do not change through handling,
3) be electrically stable under environmental changes such as temperature, humidity, etc.,
4) be electrically stable for reasonable overloads (power),
5) have a VSWR of less than 1.2 (the nearer to 1.00, the better),
6) have input and output waveguide ports that are axially in line,
7) have a small to negligible leakage power, and
8) have excellent flanges or connector surfaces.

A more complete discussion of the above is found in reference [6].

5. Measurement Results

5.1 Reflection Coefficient Magnitude

Measurements were performed on two WR15 waveguide reflectors which were manufactured at the NBS. The reflection coefficient magnitudes were approximately 0.1 and 0.024. The devices were measured each day for 10 days in order to obtain preliminary information on the standard deviations of individual runs (flange repeatability) and of day to day measurements (system random error).

The 0.024 device was made with a standard UG-385/U flange and the 0.1 device was made with a flat (non-bossed) mating surface. The waveguide precision section to which the devices were joined is a flat surface. Alignment pins were used on both flanges.

The results show that the device with the flat flange is more stable and repeatable. For the 0.1 device (flat flange) the standard deviation within runs (based on 4 individual determinations per run) was 0.02 percent of the reflection coefficient magnitude, and the standard deviation between daily averages was 0.015 percent giving a quadrature sum of 0.025 percent.

The 0.024 device exhibited some instability, and a plot of the results displays a "learning curve" (the standard deviation values decreased by an order of magnitude from start to finish) so that a components of variance analysis is not possible at present. Since the standard deviation of the daily averages for the 0.1 device is small (which implies that the measurement system is stable), the conclusion is that the UG-385/U flange is the contributing factor to the reflector instability and is indeed inferior in respect to measurement repeatability.

Additional measurements on the 0.024 device which consisted of tightening the flange bolts by proceeding in either a clockwise or counter clockwise direction around the flange by one operator reduced the standard deviation from 0.8 percent to 0.07 percent. However, when operators were changed, different values of reflection coefficient were obtained.

At present, measurements using this type of flange are unstable, and until further research on flange repeatability and the development of procedures to torque the flange bolts, no definite limits of the repeatability of reflection coefficient measurements using the UG-385/U flange can be reached.

5.2 Attenuation

The measurement of attenuation difference with a rotary-vane attenuator involves angular rotation of the center vane by a dial mechanism being set on several prescribed marks. The repeatability of such a measurement of attenuation involves these factors: (1) ability of the rotor vane to repeat the same angular displacement for a given dial setting, (2) the ability of the operator to set and read the same mark, and 3) system stability. Thus, the lack of repeatability introduces a random error in the process of several measurements. (A precise high resolution WR15 rotary-vane attenuator with a repeatability of .011 dB at a dial setting of 50 dB has been designed and constructed at the NBS.)

The procedure for an insertion loss measurement requires that the waveguide assembly be opened to accept the device-under-test. In both the closed and receptive position, the waveguide holes must be maintained in exact axial alignment to make precision measurements. The connect-disconnect and bolting of the flanges should be done with great care, especially in WR15 and smaller waveguide sizes. Laboratory benches are commercially available for holding waveguide assemblies in a stable and rigid position. The present NBS developed millimeter measurement system (fig. 21) for attenuation and impedance uses a commercial laboratory bench with moderate modifications. The attenuation calibration system is arranged in such a manner that fixed pads, inline multi-hole attenuators, directional couplers, and variable attenuators all can be inserted into the system with minimum effort.

At this time the estimate of the attenuation measurement system random error limits have not been completed, but some typical measurement results are presented in the following paragraphs.

Several commercially available waveguide devices were measured as fixed interlaboratory standards for insertion loss in WR15 waveguide measurement system at 62 and 64 GHz. One device, a directional coupler terminated with a matched load at one output port, was used as an inline fixed attenuator with a nominal value of 1 dB. The directional coupler was measured in the condition that it was received in the laboratory, that is, with a slight bend in the flange of one port. The estimated value of 3S (three times the calculated standard deviation of the mean) for six determinations taken in this circumstance was 0.129 dB. After the flange of the damaged port was realigned by machining, the calculated values of 3S for five determinations was 0.009 dB. Thus, the above measurements of insertion loss illustrate that excellent alignment of the output flanges is a must for precision measurements in millimeter waveguide.

Two fixed attenuators in WR15 waveguide measured at 62 and 64 GHz were of nominal values of 10 and 20 dB. The calculated values of 3S for five determinations of the 10 dB attenuator at 62 GHz and of a 20 dB attenuator at 64 GHz was 0.023 dB and 0.012 dB, respectively. The measurement precision was better with the 20 dB attenuator due to better flange alignment.

The insertion loss or attenuation of a twenty-eight inch section of commercial silver WR15 waveguide was measured at 64 GHz. The value of 3S for five determinations was 0.012 dB. The nominal value of attenuation of the twenty-eight inch section was 1.5 dB, or about 0.05 dB/inch.

The authors extend their appreciation to R.W. Beatty for his helpful suggestions regarding this paper and to G.C. Counas and R.D. Hunter for their help in the system instrumentation and measurements.

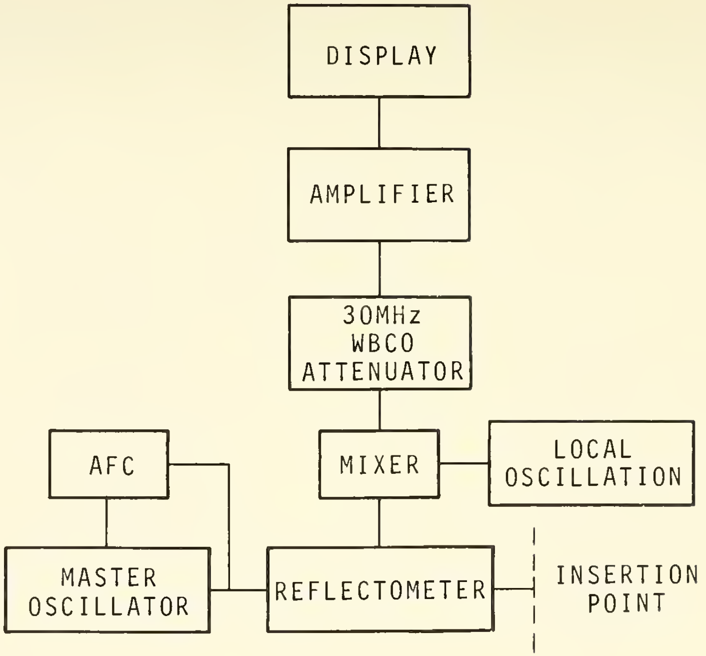

Figure 1. Block diagram of the reflection coefficient magnitude subsystem using an i-f receiver.

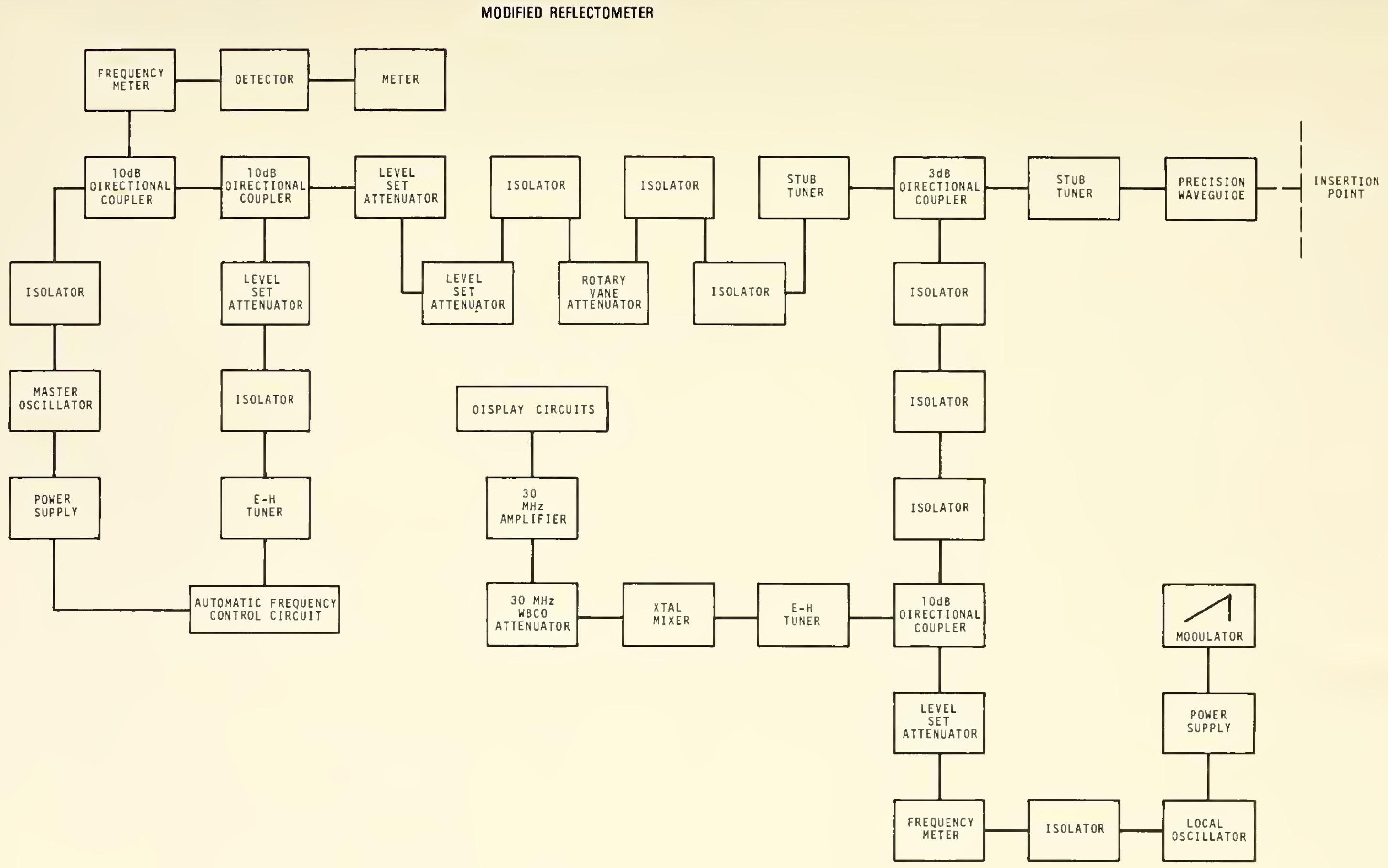

Figure 2. Detailed diagram of the reflection coefficient magnitude subsystem.

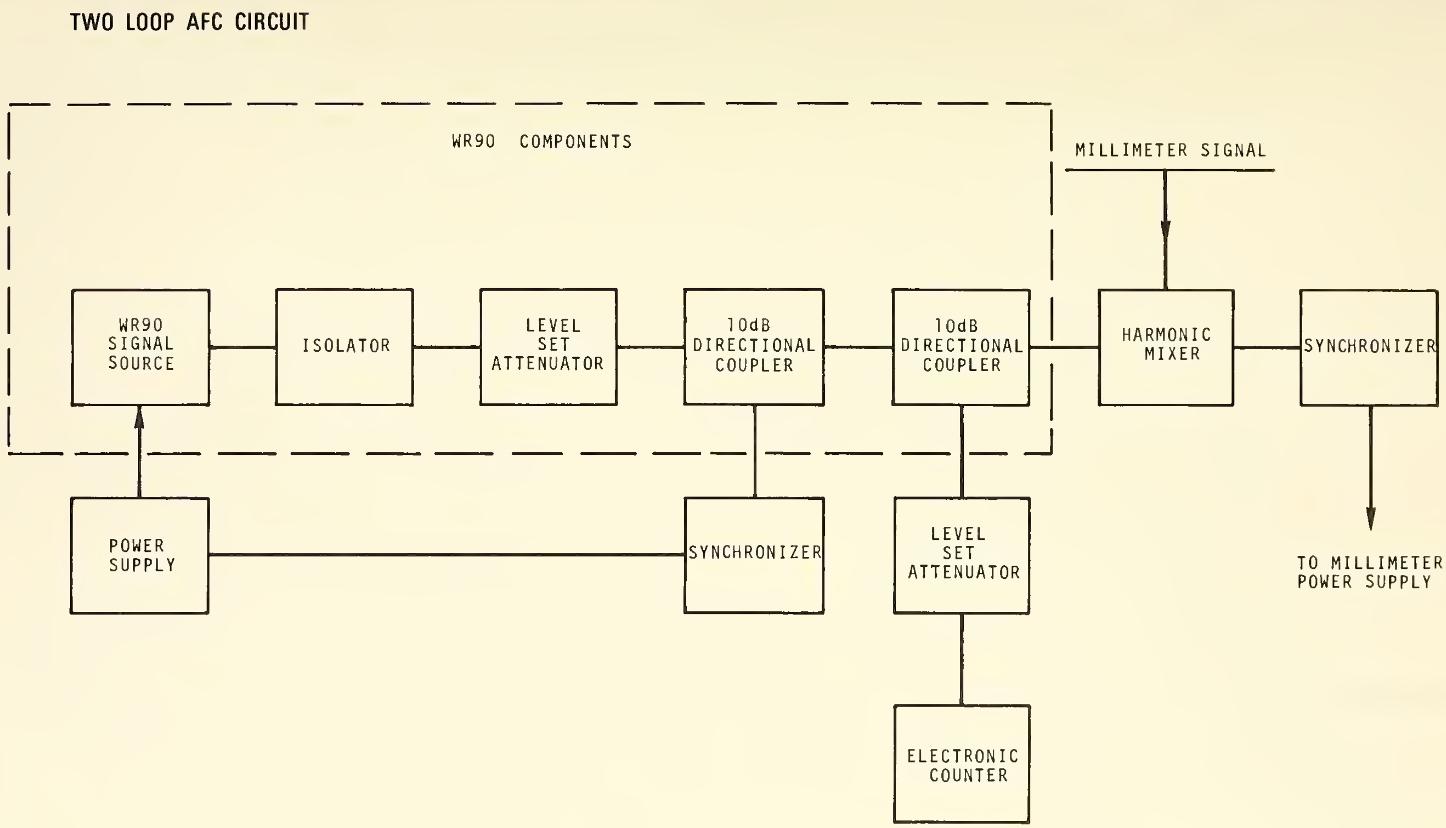

Figure 3. Detailed diagram of the two-loop automatic frequency control network.

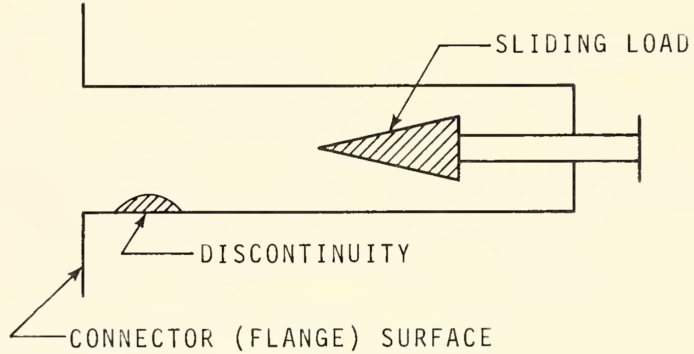

Figure 4. Waveguide termination.

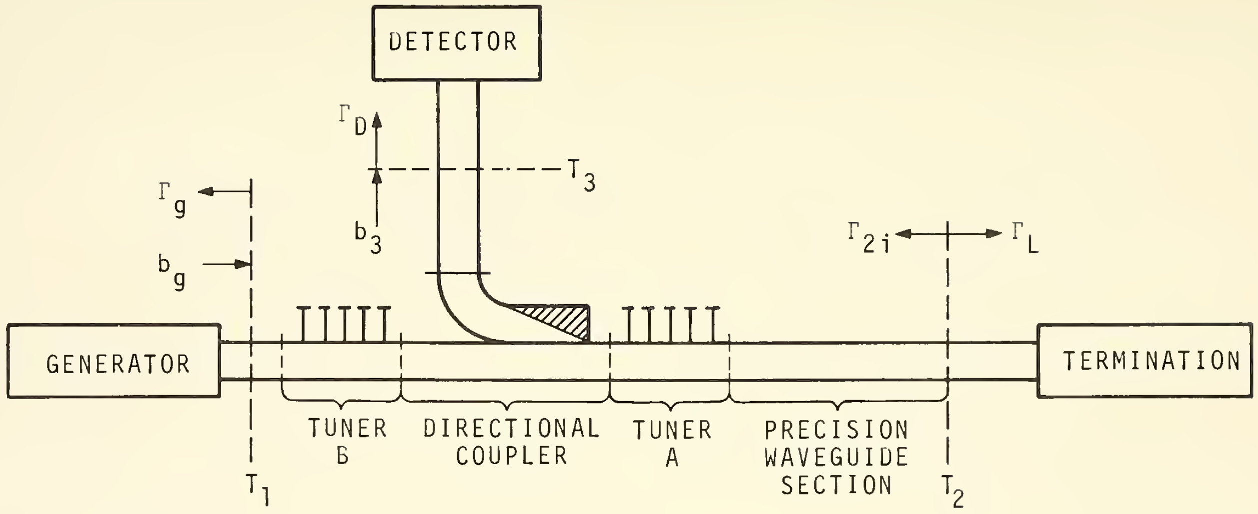

Figure 5. Diagram of a tunable, single-directional coupler reflectometer (modified reflectometer).

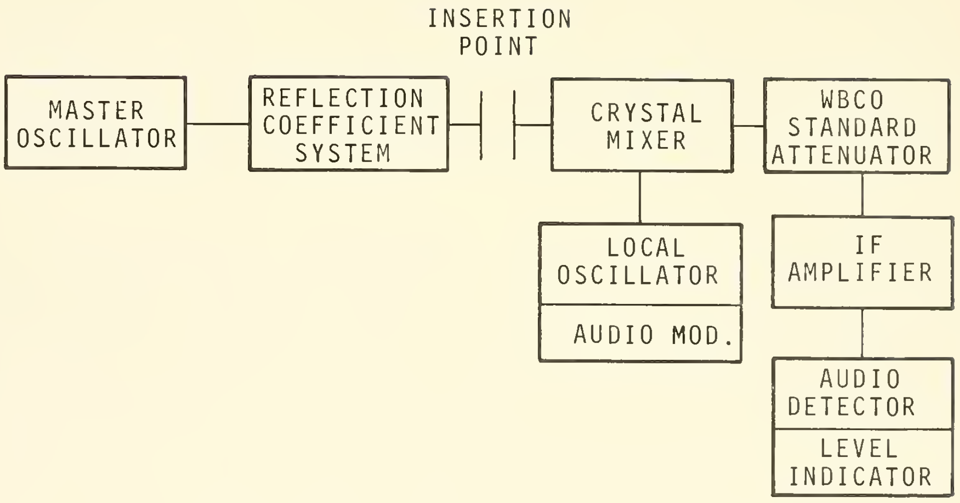

Figure 6. Block diagram of the i-f series substitution attenuation subsystem.

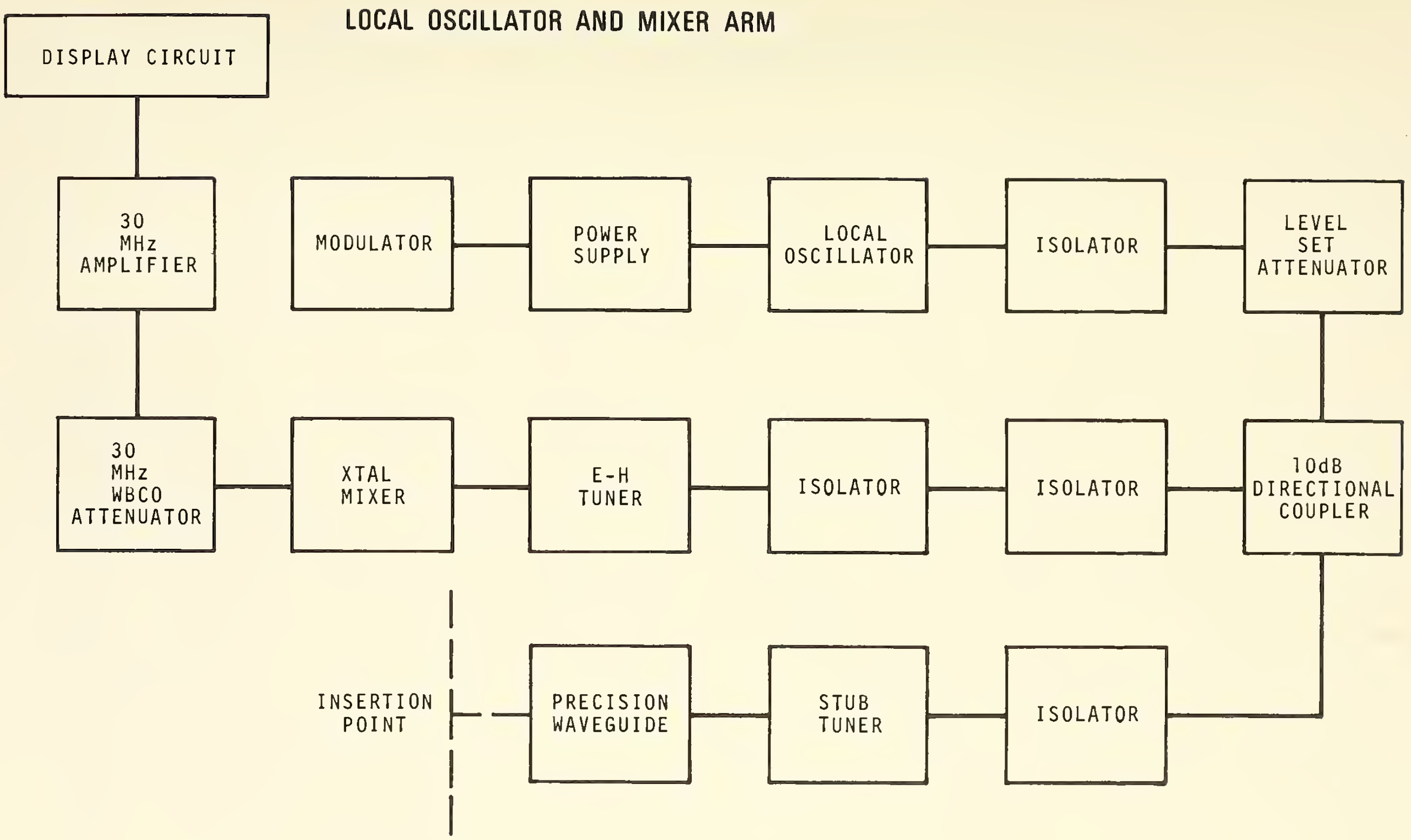

Figure 7. Detailed diagram of the rf receiver of the attenuation subsystem.

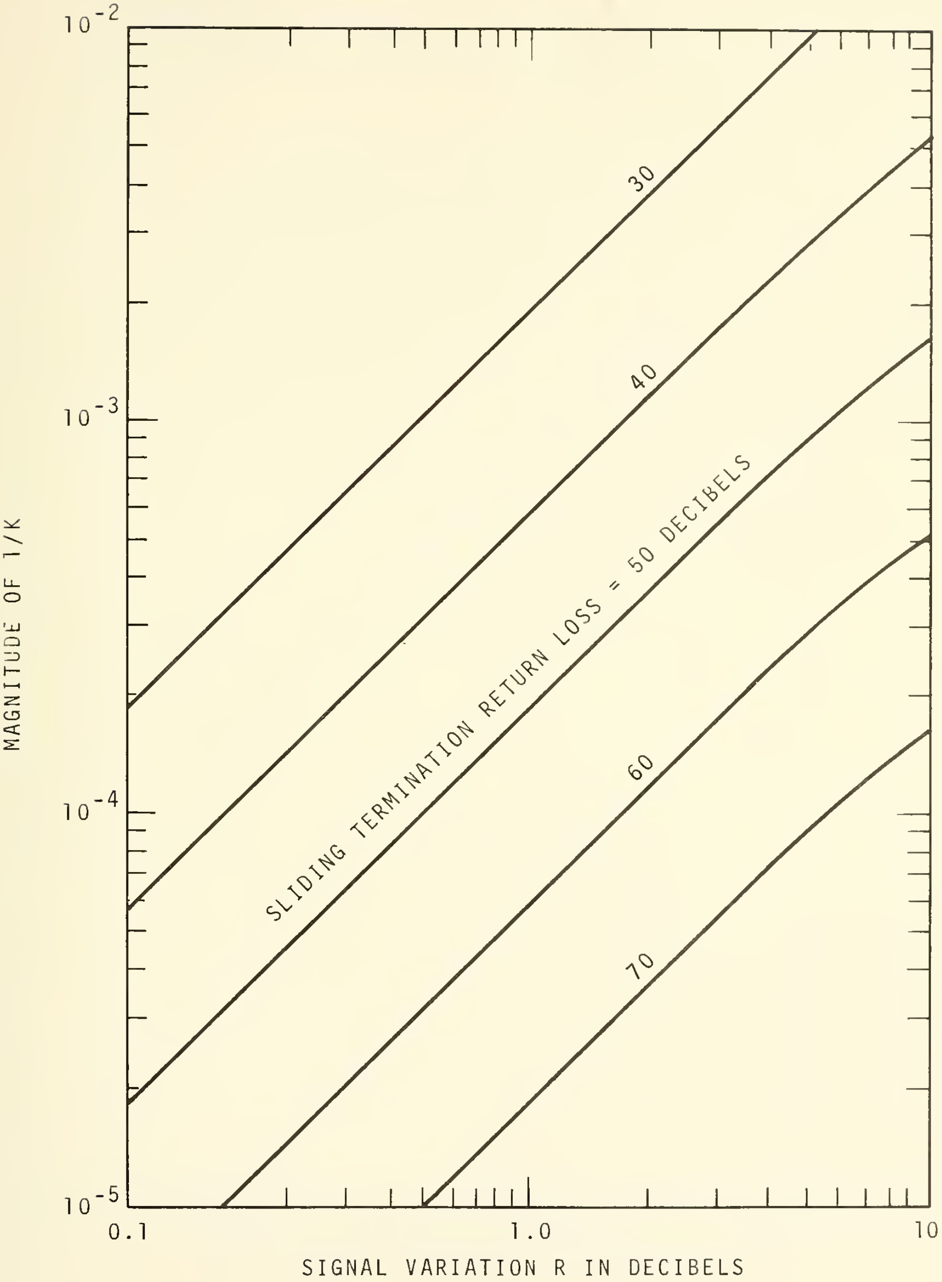

Figure 8. Graph for estimating the magnitude of 1/K given a response variation R when sliding a load with return losses of 30 to 70 decibels.

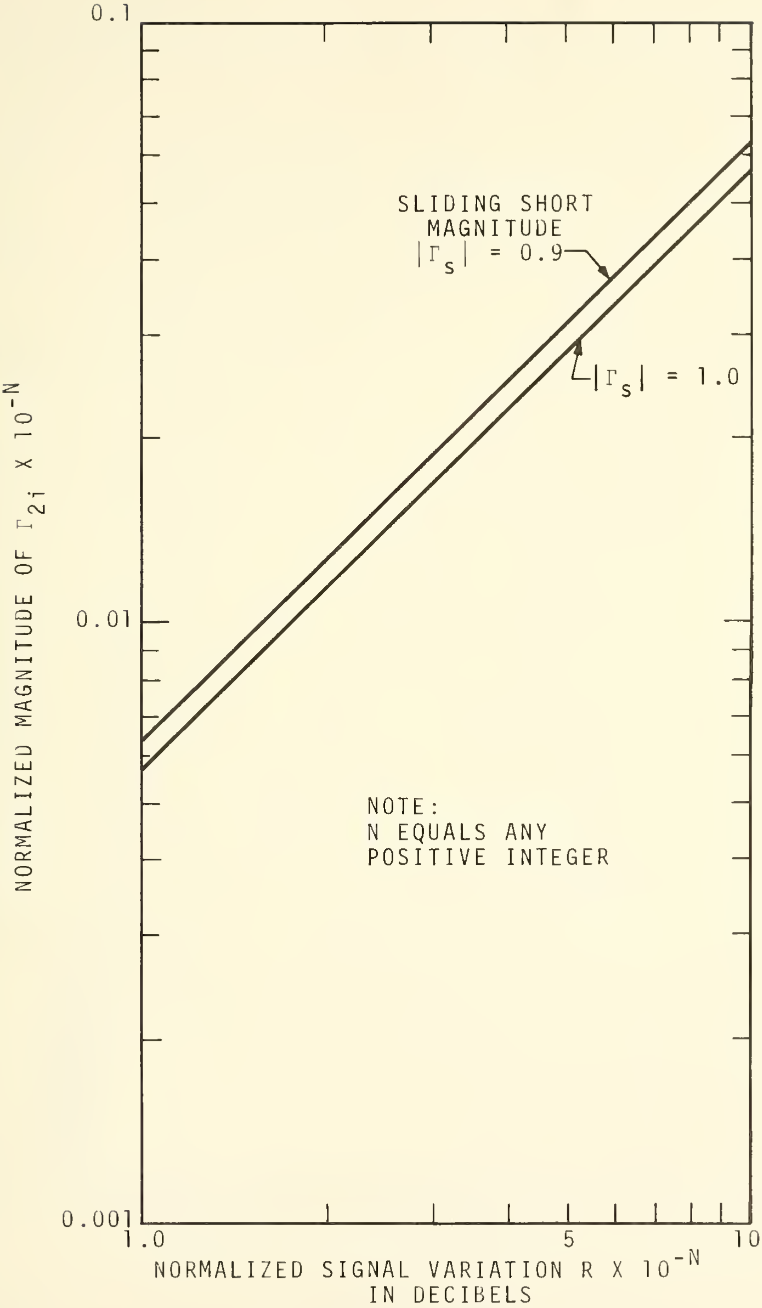

Figure 9. Graph for estimating the equivalent generator impedance for a given response variation $R \times 10^{-N}$ when sliding a short-circuit termination.

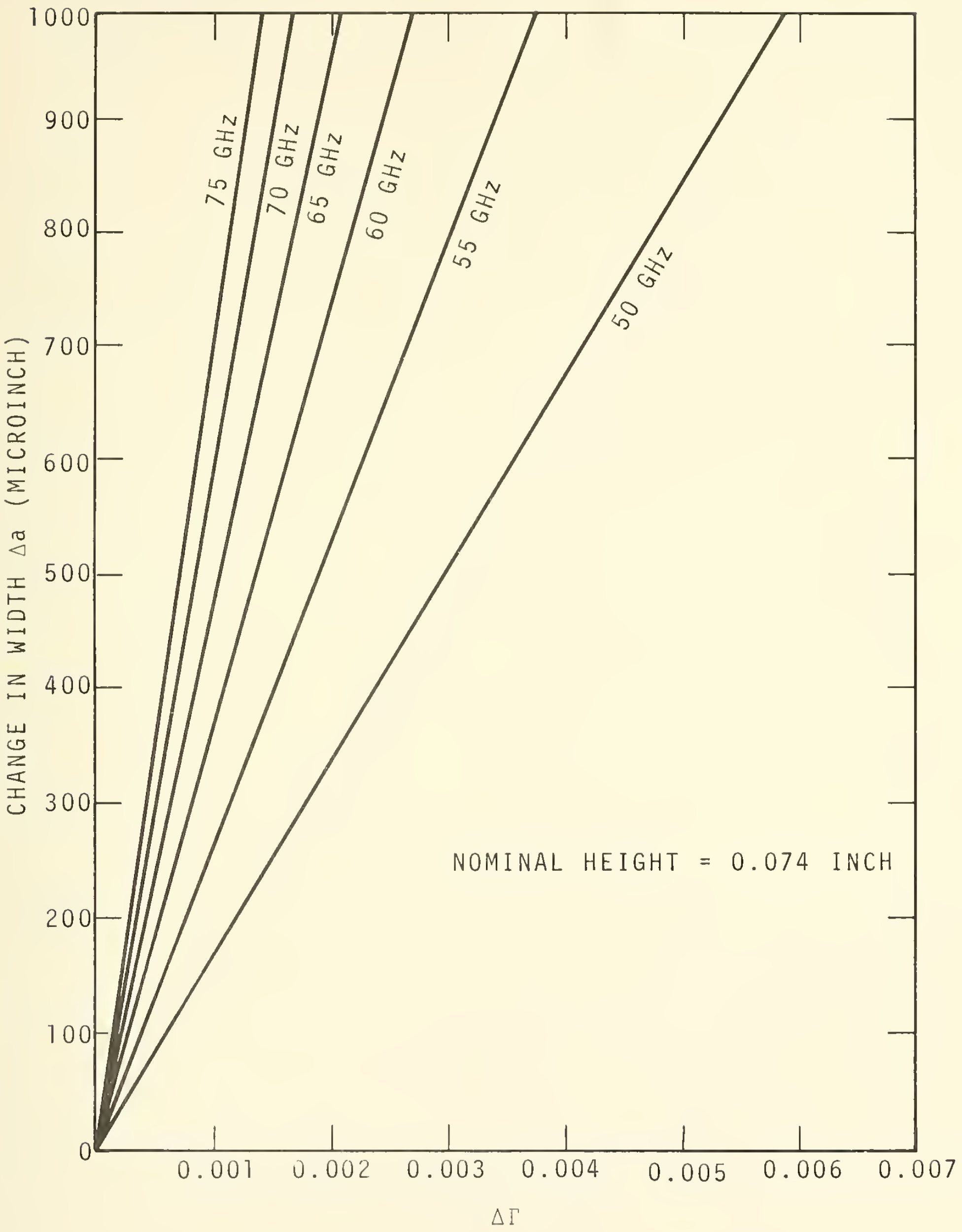

Figure 10. Change in reflection coefficient magnitude versus dimension change in the nominal waveguide width of 0.148 inch.

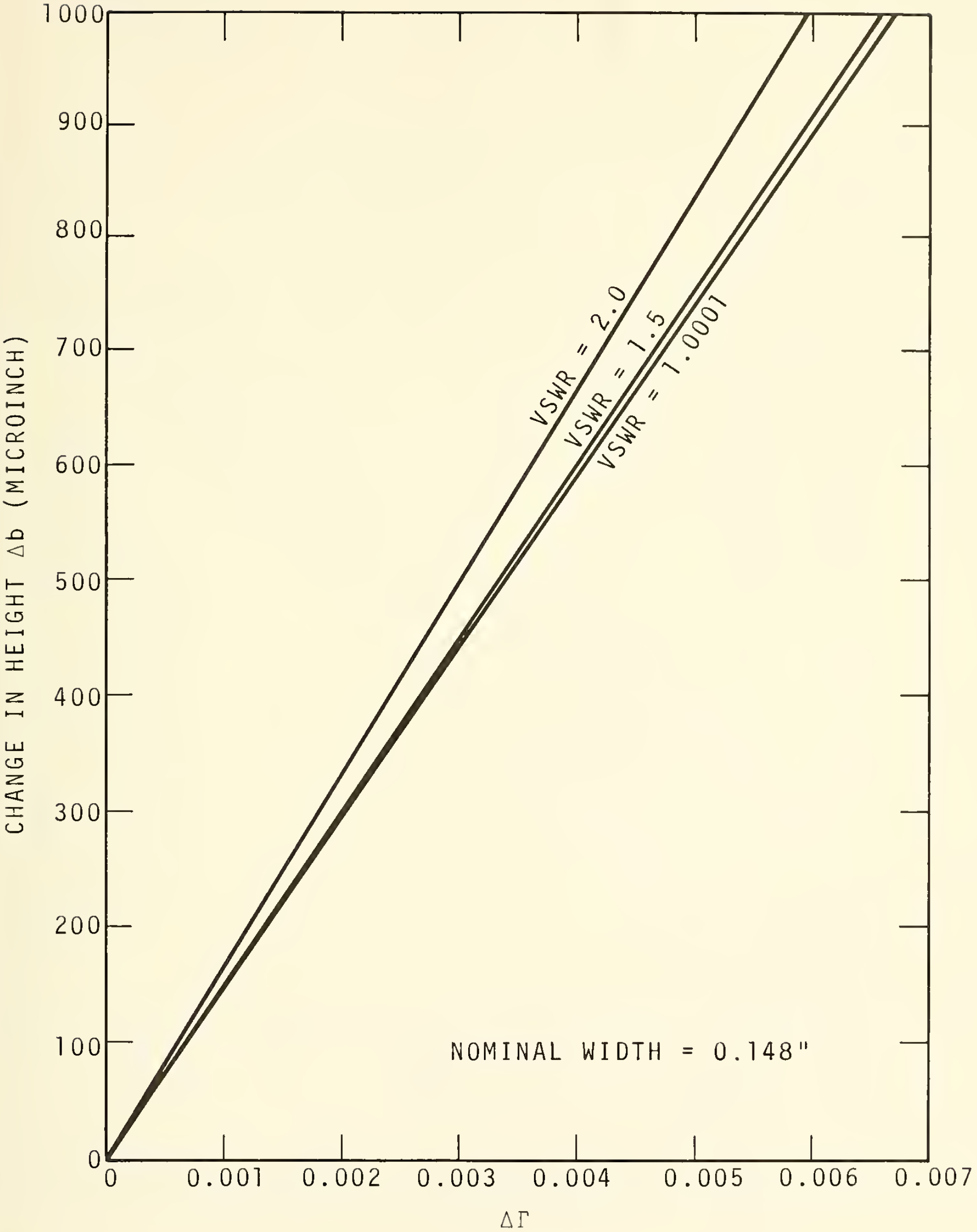

Figure 11. Change in reflection coefficient magnitude versus dimensional change in the nominal waveguide height of 0.074 inch.

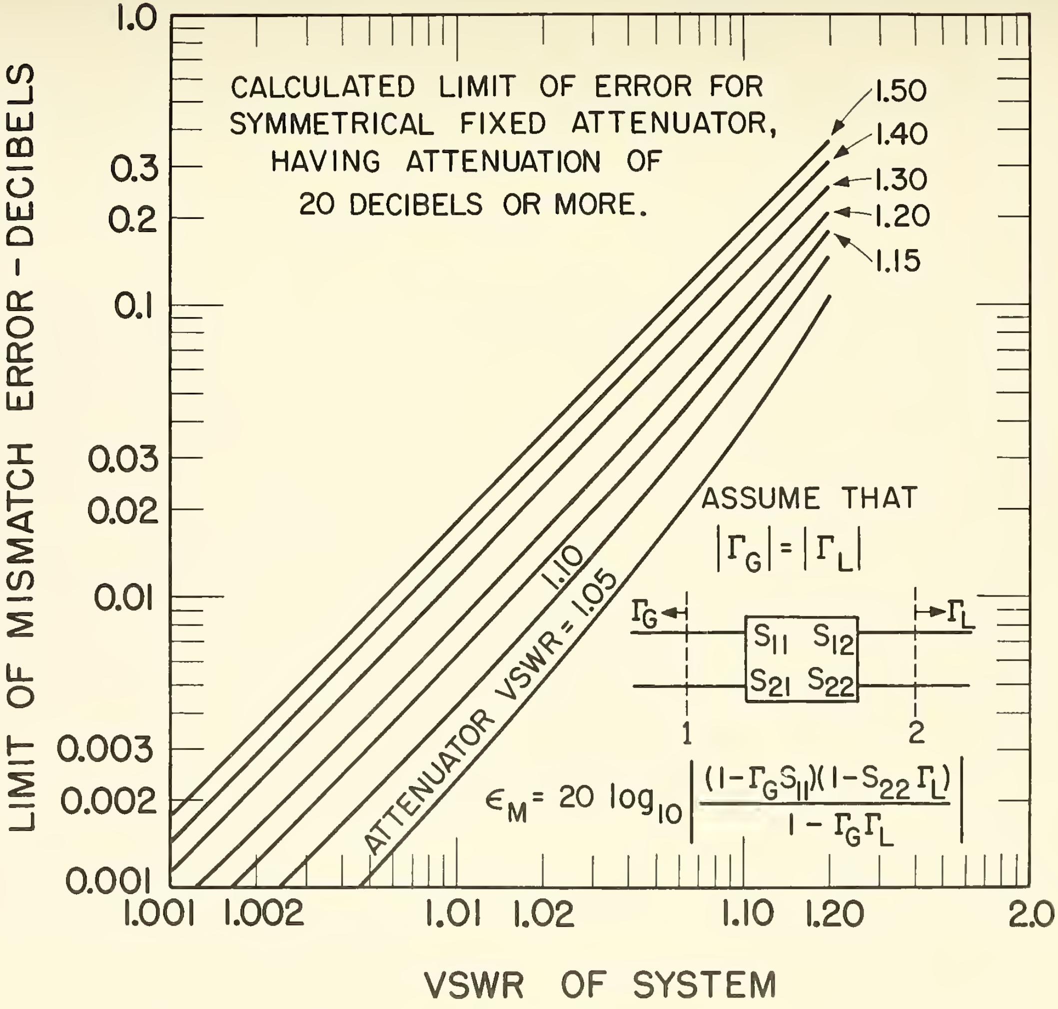

Figure 12. Graph for estimating mismatch error limits when the attenuation and system VSWR is given.

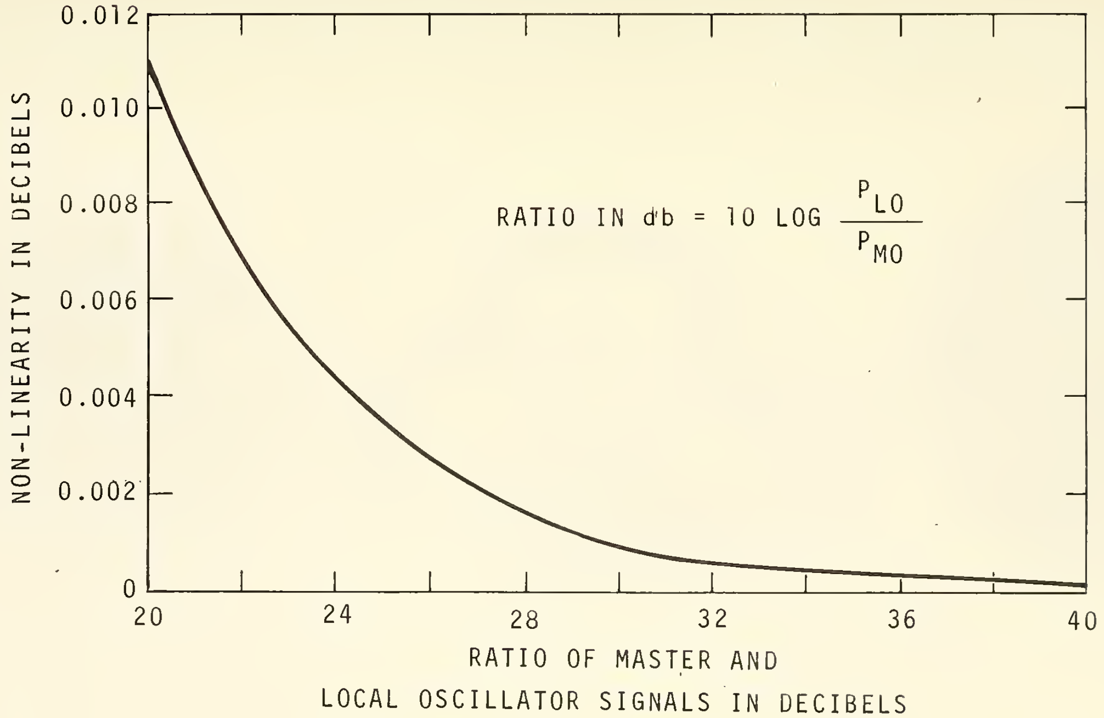

Figure 13. Theoretical mixer power conversion non-linearity versus master-local oscillator power ratio.

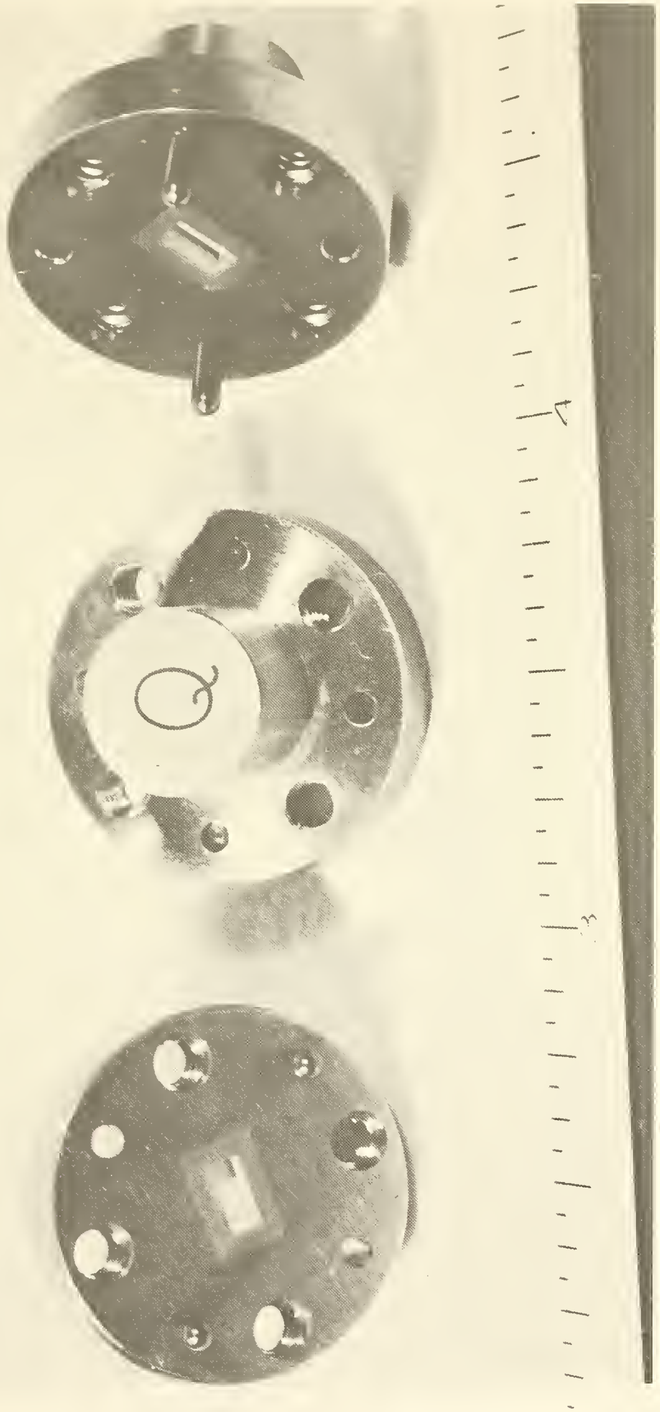

Figure 14. Quarter-wavelength short-circuited waveguide standards.

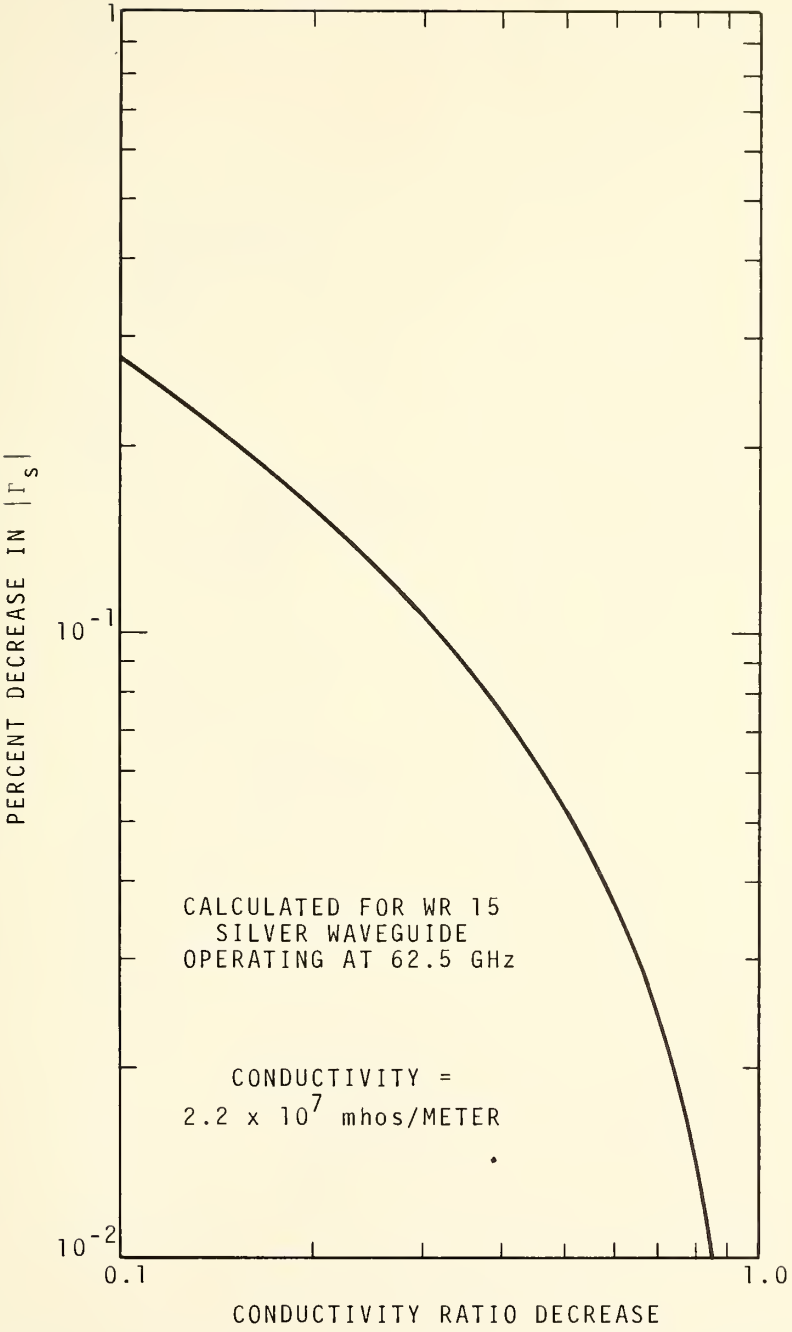

Figure 15. Graph for estimating the change in reflection coefficient of a quarterwave short circuit versus conductivity confidence interval (the relative error substracted from unity).

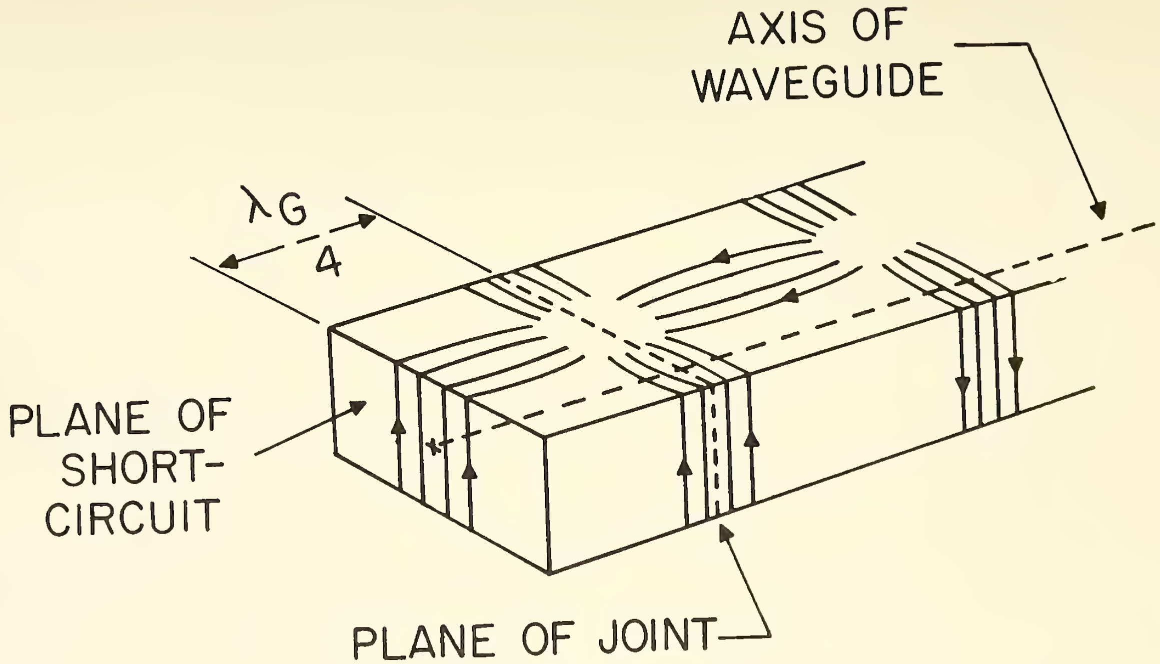

Figure 16. Current distribution for a rectangular TE_{10} mode short-circuited waveguide.

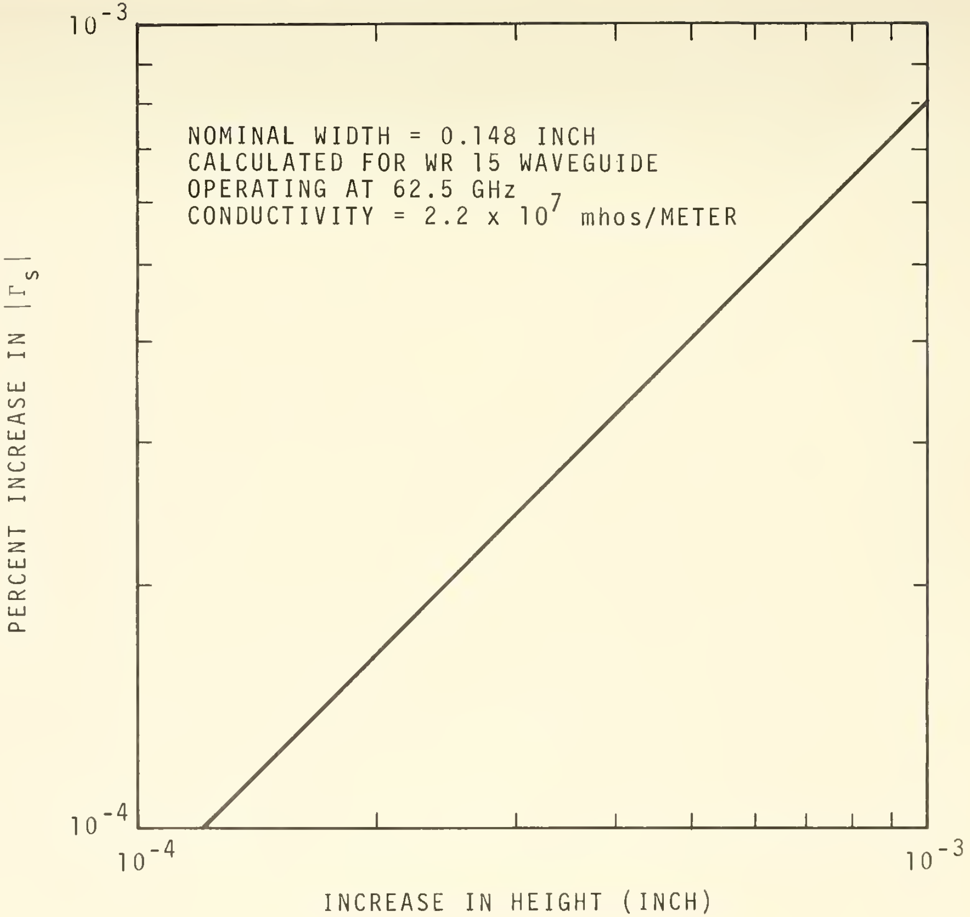

Figure 17. Graph for estimating the change in reflection coefficient magnitude of a quarterwave short circuit versus dimensional deviation from height dimension of 0.074 inch.

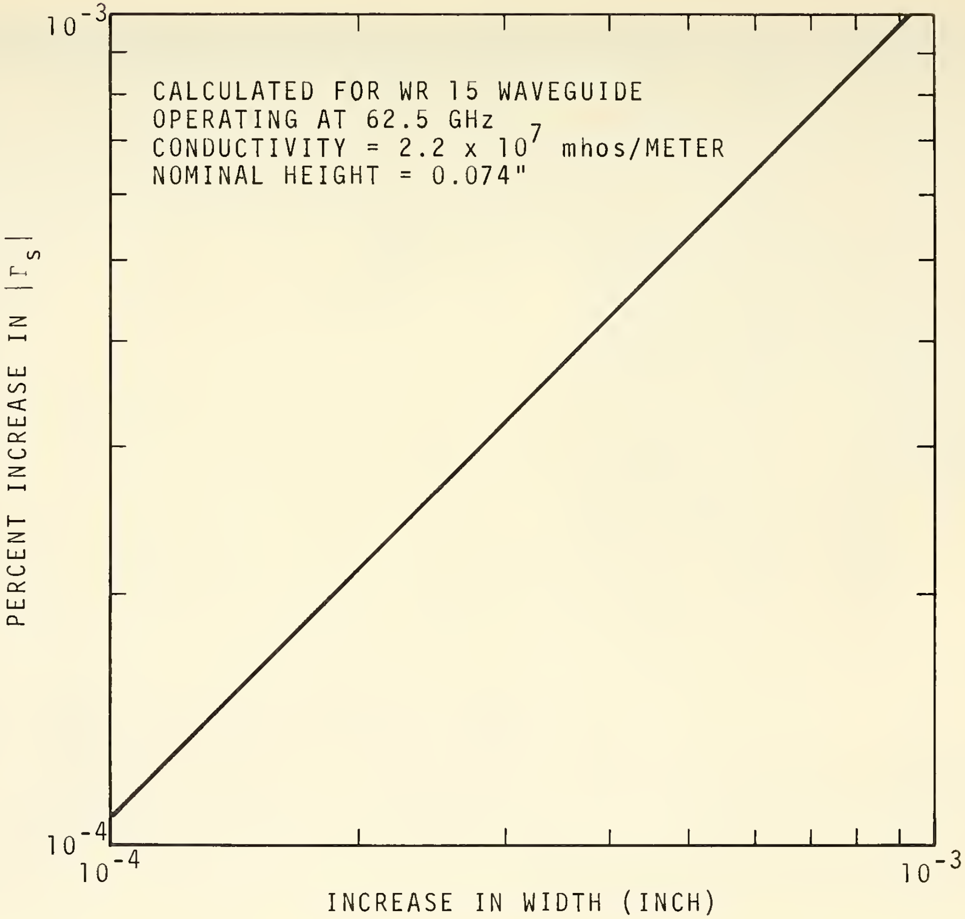

Figure 18. Graph for estimating the change in reflection coefficient magnitude of a quarterwave short circuit versus dimensional deviation from nominal width dimension of 0.148 inch.

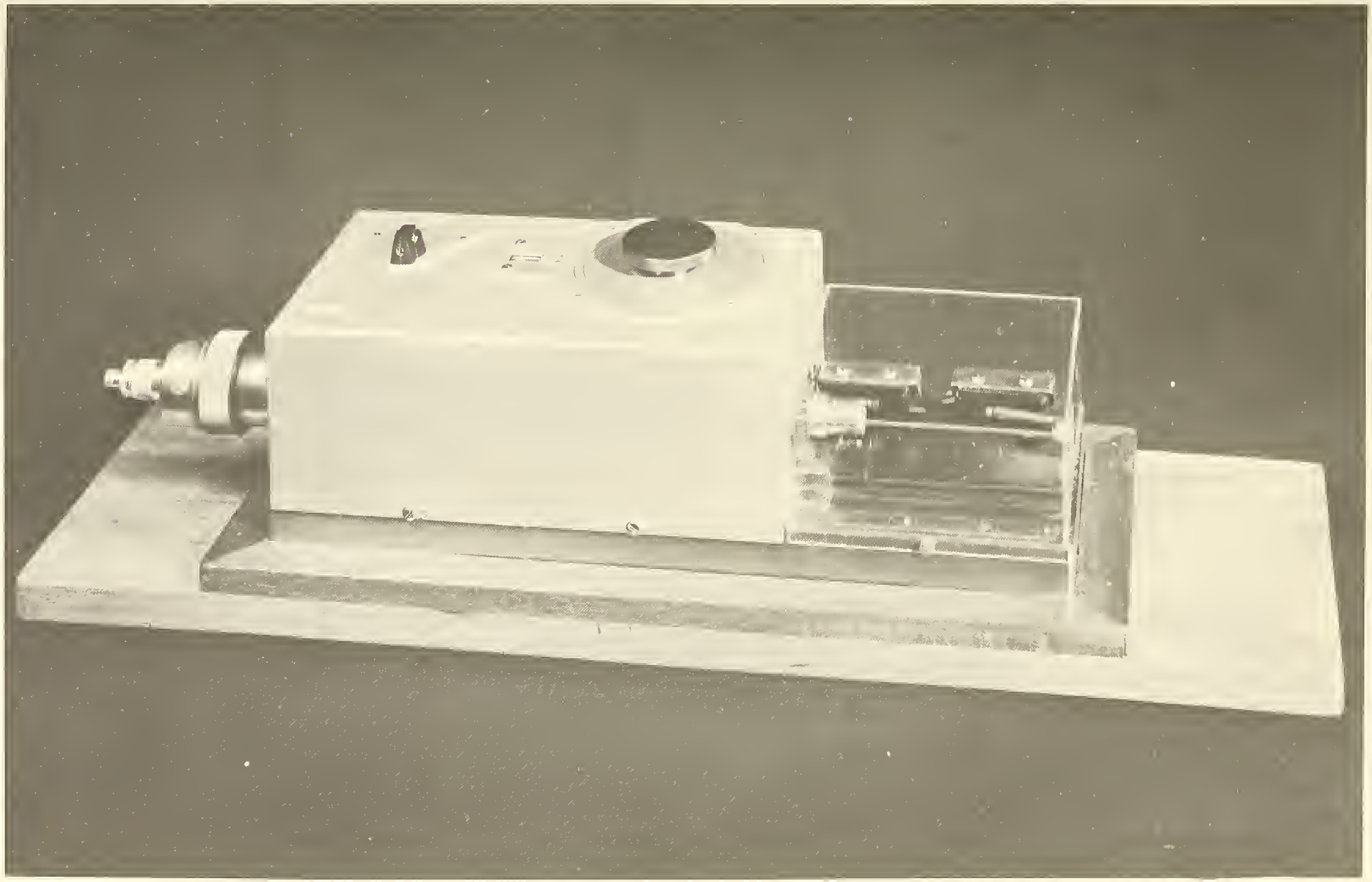

Figure 19. Waveguide-Below-Cutoff attenuator.

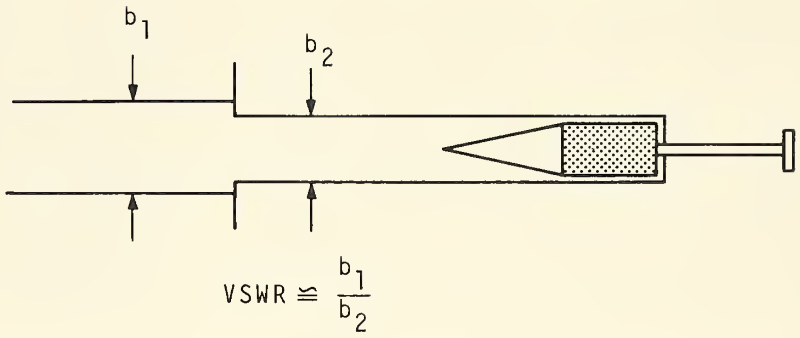

Figure 20. Typical change in narrow dimension of rectangular waveguide used for interlaboratory reflection standards.

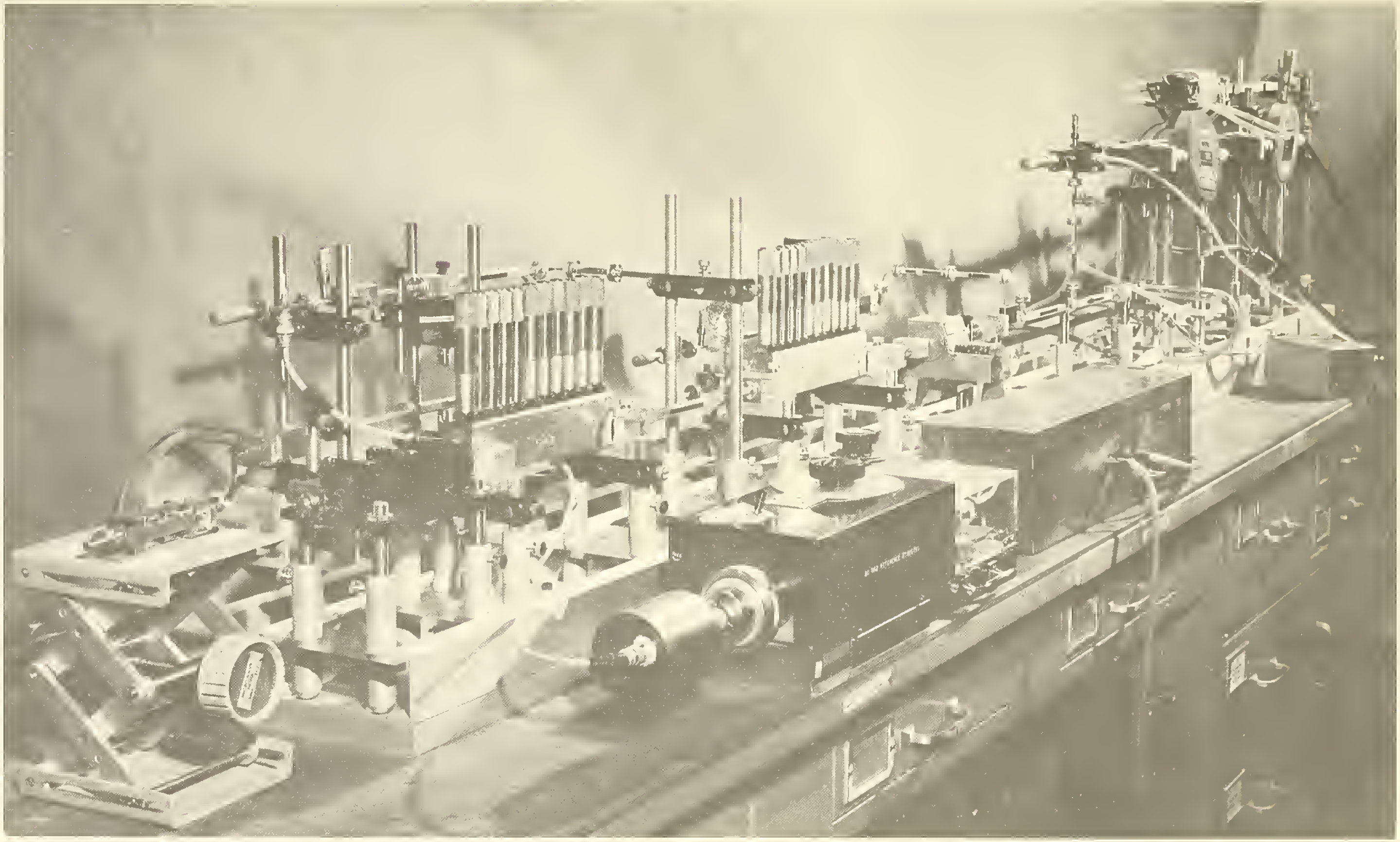

Figure 21. WR15 reflectometer and associated support hardware.

APPENDIX A

To illustrate the statement in section 2.1.2 that the average reflection coefficient magnitude $|\Gamma|_{ave}$ is associated with that element which has the largest reflection, consider the following lossless case (for definitions of losslessness see [29], p. 48) of a termination with a fixed discontinuity Γ_D and a sliding load Γ_L.

It can be shown [30, 31] that

$$|\Gamma|_{max} = \frac{|\Gamma_D| + |\Gamma_L|}{1 + |\Gamma_D \Gamma_L|}$$

and

$$|\Gamma|_{min} = \frac{|\Gamma_D| - |\Gamma_L|}{1 - |\Gamma_D \Gamma_L|} \qquad |\Gamma_D| > |\Gamma_L|$$

or

$$|\Gamma|_{min} = \frac{|\Gamma_L| - |\Gamma_D|}{1 - |\Gamma_D \Gamma_L|} \qquad |\Gamma_L| > |\Gamma_D|$$

where $|\Gamma|_{max}$ and $|\Gamma|_{min}$ correspond to the measured maximum and minimum reflection coefficients. Then, the average reflection coefficient magnitude

$$|\Gamma|_{ave} = \frac{1}{2}\left(|\Gamma|_{max} + |\Gamma|_{min}\right)$$

$$= |\Gamma_D| \frac{(1 - |\Gamma_L|^2)}{1 - |\Gamma_D \Gamma_L|^2}, \qquad |\Gamma_D| > |\Gamma_L|$$

or

$$= |\Gamma_L| \frac{(1 - |\Gamma_D|^2)}{1 - |\Gamma_D\Gamma_L|^2}, \qquad |\Gamma_L| > |\Gamma_D|$$

is in either case a first order approximation to the largest reflection coefficient.

APPENDIX B

Estimated Systematic Error Limits for WR15 Attenuation Measurements

The following estimated error limits are based on tolerances for the NBS WR15 components and systems.

Converter (Mixer) Error	±0.003
Noise up to 40 dB measured attenuation	±0.004
Noise up to 50 dB measured attenuation	±0.020 dB
30 MHz Standard Attenuator	
Loading effects	±0.001 dB
Mode purity	±0.001 dB
Dimensional Tolerance	±0.002 dB/20 dB

Mismatch Error vs. Attenuator VSWR

(System VSWR at insertion point = 1.02)

Attenuator VSWR	Mismatch Error (dB)
1.05	±0.005
1.10	±0.008
1.15	±0.013
1.20	±0.017

Total Systematic Error (dB)

Dial Setting (dB)	Attenuator VSWR			
	1.05	1.10	1.15	1.20
10	±0.012	±0.015	±0.020	±0.024
20	±0.012	±0.015	±0.020	±0.024
30	±0.014	±0.017	±0.022	±0.026
40	±0.018	±0.021	±0.026	±0.030
50	±0.036	±0.039	±0.044	±0.048

APPENDIX C

Estimated Systematic Error Limits ($\Delta\Gamma$) for WR15 Reflection Coefficient Magnitude ($|\Gamma|$) Measurements

The following estimated error limits are based on tolerances for the NBS WR15 components and systems.

$|\Gamma| \geq 0.025$

Tuning Error	
Directivity	$\pm 0.00015\ (1 + |\Gamma|)$
Γ_{2i}	$\pm 0.00012\ (1 + |\Gamma|)$
Converter Error	$\pm 0.00035\ |\Gamma|$
30 MHz Standard Attenuator	$\pm 0.00046\ |\Gamma|$
Reflection Coefficient Magnitude Standard	$\pm 0.0003\ |\Gamma|$
Precision Section	± 0.0006
Total Error	$\pm 0.00087 + 0.00138\ |\Gamma|$
Reported Estimated Error	$\Delta\Gamma = \pm(1 + 1.5|\Gamma|) \times 10^{-3}$

$|\Gamma| < 0.025$

Converter Error	$\pm 0.00105\ |\Gamma|$
30 MHz Standard Attenuator	$\pm 0.00138\ |\Gamma|$
Total Error	$\pm 0.00087 + 0.0030\ |\Gamma|$
Reported Estimated Error	$\Delta\Gamma = \pm(1 + 3|\Gamma|) \times 10^{-3}$

APPENDIX D

Machine drawings for 11 stub tuner for 55-65 GHz, WR15.

Figures 22(a), 22(b), 22(c).

Certain commercial equipment and materials are identified in this paper in order to adequately specify the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.

ORIGINAL DATE OF DRAWING

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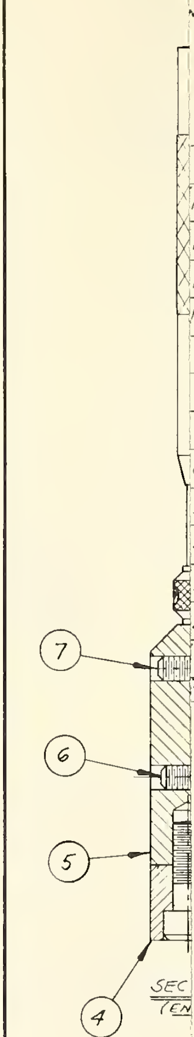
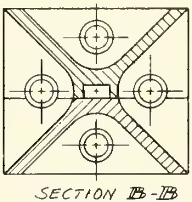


LIST OF PARTS

* STOCK ITEMS

ECE No.	NOMENCLATURE	No. REQ'D
13	DIFFERENTIAL SCREW TRANSLATOR (MICROMETER 0"-.050) LANSING PRODUCT CAT. 306-1/69 # 22.505 (MODIF. "B")	4
12	DIFFERENTIAL SCREW TRANSLATOR (MICROMETER 0"-.050") LANSING PRODUCT CAT. 306-1/69 # 22505 (MODIF. "A")	7
11	BUSHING MAT'L ~ HARDENED STEEL	8
10	"NO-MAR" STAINLESS STEEL SET SCREW, # 6-32UNC, 9/32 LONG PIC CAT. No. CB-15 (MODIFIED: NYLON REPLACED BY .050 D. BRASS PIN)	11
9	SPINDLE TIP WITH STUB MAT'L ~ SPINDLE TIP: FREE CUTTING BRASS; STUB: DRILL ROD	11
8	CONTACT SPRING MAT'L ~ PHOSPHOR BRONZE	11
7	STEEL SET SCREW # 6-32 UNC, 1/4 LONG FLAT POINT	11
6	"NO-MAR" STAINLESS STEEL SET SCREW # 6-32 UNC 9/32 LONG PIC CAT. No. CS-15 (MODIFIED: NYLON REPLACED BY BRASS)	11
5	HOUSING, TOP SECTION MAT'L ~ FREE CUTTING BRASS	1
4	HOUSING, BOTTOM SECTION MAT'L ~ FREE CUTTING BRASS	1
3	STEEL HEX. SOCKET HEAD SCREW, # 8-32 UNC 1/2 LONG	22
2	STEEL HEX. SOCKET HEAD SCREW, # 3-48 UNC 5/8 LONG	8
1	HELICOIL INSERT # 3-48 UNC, STAINLESS STEEL 0.248 LONG	8



SECTION B-B
(ENLARGED × 2)

PIECE NO	NOMENCLATURE	NO REQ'D

NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER, COLORADO, 80302

11 STUB TUNER

FOR 55-65 GHz, WR-15 (RG-98/U)

MODEL I	TYPE	SCALE 1/1
DIMENSIONS IN INCHES (Unless otherwise specified) TOLERANCES (Unless otherwise specified) DECIMALS ±.005 FRACTIONS ±.015 ANGLES ±1/2°	DRAFTSMAN Victor Lecinski	CHECKER
	PROJECT ENGR BILL C. YATES	PROJECT ENGR A.P. WEIDMAN
	SUBMITTED BY	CHIEF SEC....
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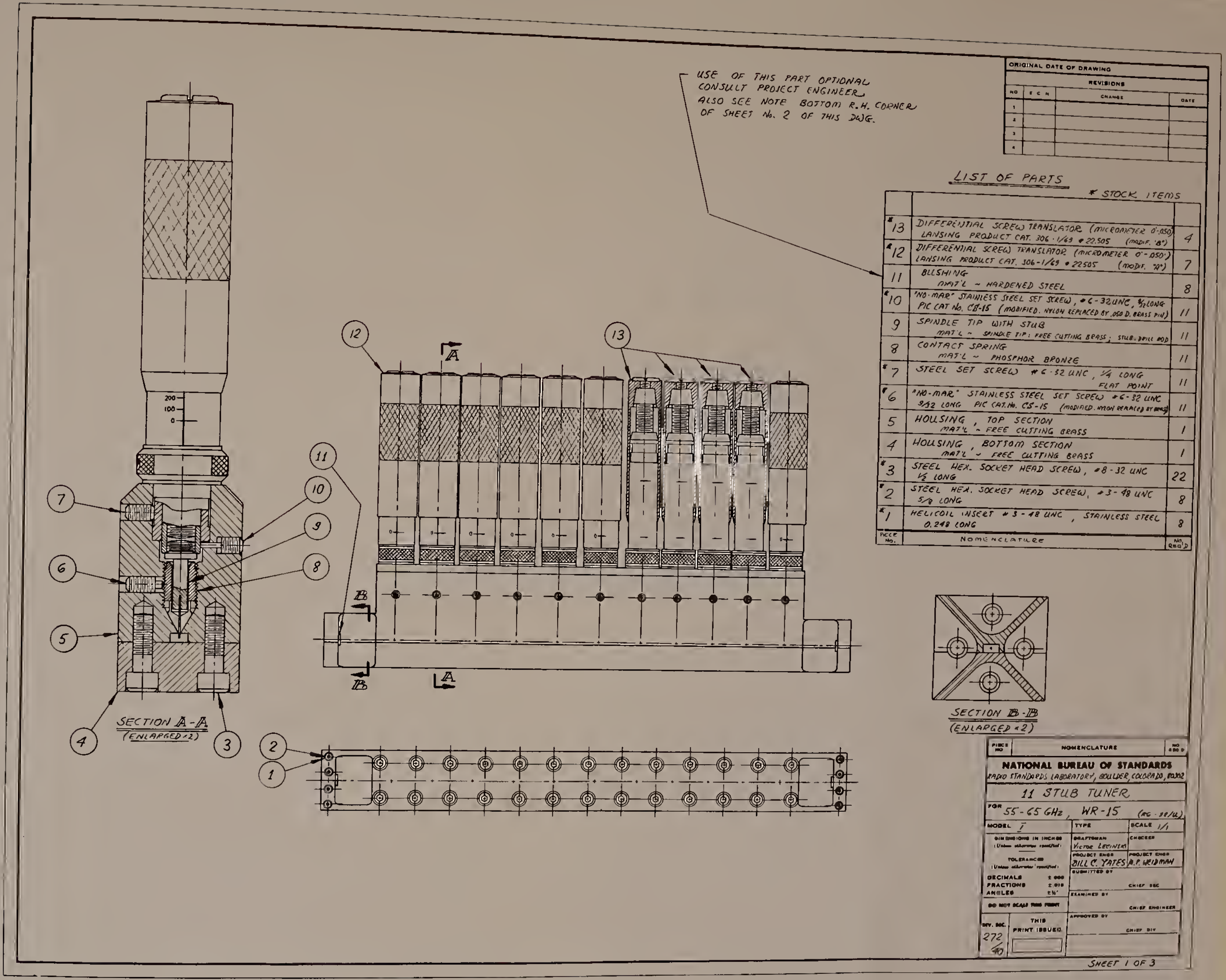
DIV. SEC. 272/40 — THIS PRINT ISSUED	APPROVED BY	CHIEF. DIV ....

SHEET 1 OF 3

Figure 22(a



USE OF THIS PART OPTIONAL
CONSULT PROJECT ENGINEER.
ALSO SEE NOTE BOTTOM R.H. CORNER
OF SHEET No. 2 OF THIS DWG.

ORIGINAL DATE OF DRAWING

REVISIONS			
NO	E C N	CHANGE	DATE
1			
2			
3			
4			

LIST OF PARTS

* STOCK ITEMS

PIECE No.	NOMENCLATURE	NO. REQ'D
*13	DIFFERENTIAL SCREW TRANSLATOR (MICROMETER 0'-.050) LANSING PRODUCT CAT. 306-1/69 # 22.505 (MODIF. "B")	4
*12	DIFFERENTIAL SCREW TRANSLATOR (MICROMETER 0'-.050') LANSING PRODUCT CAT. 306-1/69 # 22505 (MODIF. "A")	7
11	BUSHING MAT'L ~ HARDENED STEEL	8
*10	"NO-MAR" STAINLESS STEEL SET SCREW, #6-32UNC, 9/32 LONG PIC CAT No. CS-15 (MODIFIED. NYLON REPLACED BY .050 D. BRASS PIN)	11
9	SPINDLE TIP WITH STUB MAT'L ~ SPINDLE TIP: FREE CUTTING BRASS; STUB: DRILL ROD	11
8	CONTACT SPRING MAT'L ~ PHOSPHOR BRONZE	11
*7	STEEL SET SCREW #6-32 UNC, 1/4 LONG FLAT POINT	11
*6	"NO-MAR" STAINLESS STEEL SET SCREW #6-32 UNC 9/32 LONG PIC CAT. No. CS-15 (MODIFIED. NYLON REPLACED BY BRASS)	11
5	HOUSING, TOP SECTION MAT'L ~ FREE CUTTING BRASS	1
4	HOUSING, BOTTOM SECTION MAT'L ~ FREE CUTTING BRASS	1
*3	STEEL HEX. SOCKET HEAD SCREW, #8-32 UNC 1/2 LONG	22
*2	STEEL HEX. SOCKET HEAD SCREW, #3-48 UNC 5/8 LONG	8
*1	HELICOIL INSERT #3-48 UNC, STAINLESS STEEL 0.248 LONG	8

PIECE NO	NOMENCLATURE	NO REQ'D

NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER, COLORADO, 80302

11 STUB TUNER

FOR 55-65 GHz, WR-15 (RG-98/U)

MODEL I	TYPE	SCALE 1/1
DIMENSIONS IN INCHES (Unless otherwise specified)	DRAFTSMAN Victor Lecinski	CHECKER
TOLERANCES (Unless otherwise specified) DECIMALS ±.000 FRACTIONS ±.010 ANGLES ±½°	PROJECT ENGR BILL C. YATES	PROJECT ENGR R.P. WEIDMAN
	SUBMITTED BY CHIEF SEC	
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Figure 22(a).

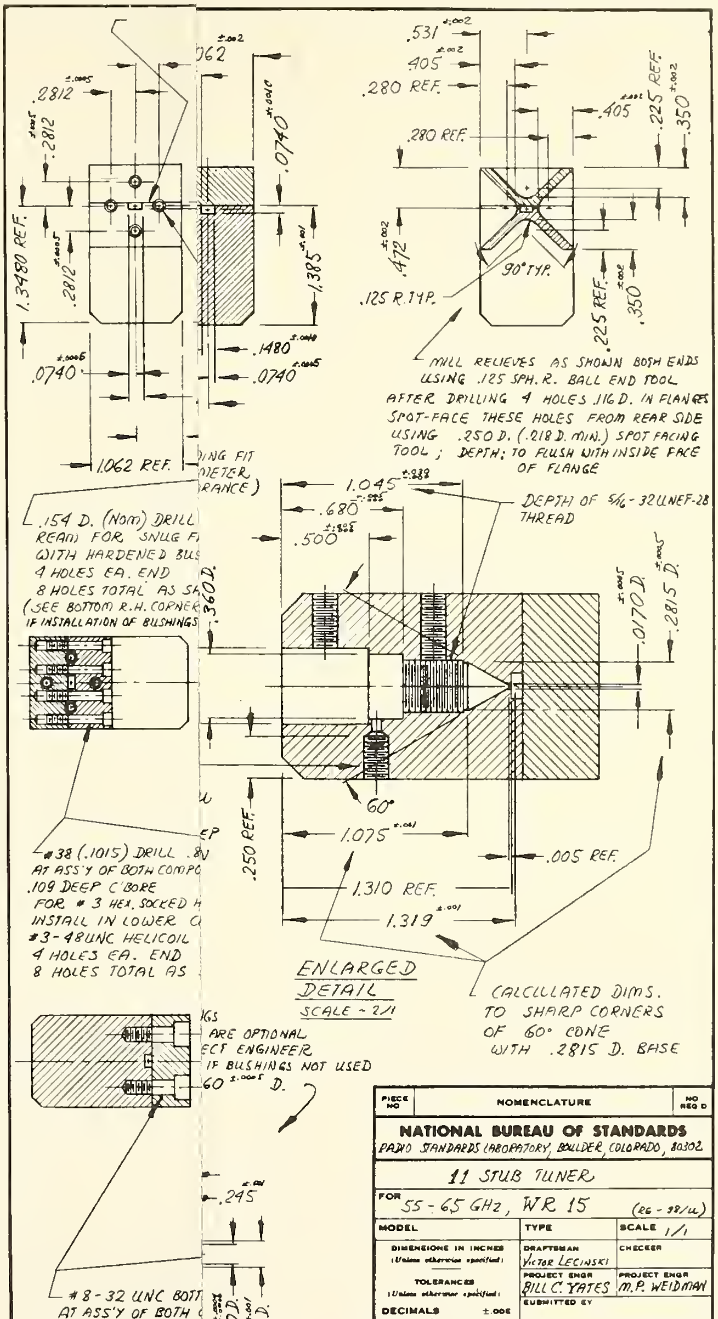
.062 ±.002
.2812 ±.0005
.2812 ±.0005
.0740 ±.0010
1.3480 REF.
.2812 ±.0005
1.385 ±.001
.1480 ±.0010
.0740 ±.0005
.0740 ±.0005
1.062 REF.
.531 ±.002
.405 ±.002
.280 REF.
.405 ±.002
.225 REF.
.350 ±.002
.280 REF.
.472 ±.002
90° TYP.
.125 R. TYP.
.225 REF.
.350 ±.002
MILL RELIEVES AS SHOWN BOTH ENDS USING .125 SPH. R. BALL END TOOL
AFTER DRILLING 4 HOLES .116 D. IN FLANGES SPOT-FACE THESE HOLES FROM REAR SIDE USING .250 D. (.218 D. MIN.) SPOT FACING TOOL ; DEPTH: TO FLUSH WITH INSIDE FACE OF FLANGE
.154 D. (NOM) DRILL REAM FOR SNUG FI WITH HARDENED BUS 4 HOLES EA. END 8 HOLES TOTAL AS SH (SEE BOTTOM R.H. CORNER IF INSTALLATION OF BUSHINGS
ING FIT METER RANCE)
1.045
.680
.500
DEPTH OF 5/16-32UNEF-2B THREAD
.360 D.
.0170 D. ±.0005
.2815 D. ±.0005
60°
1.075 ±.001
.250 REF.
.005 REF.
1.310 REF.
1.319 ±.001
#38 (.1015) DRILL .8 AT ASS'Y OF BOTH COMPO .109 DEEP C'BORE FOR #3 HEX. SOCKED H INSTALL IN LOWER C #3-48UNC HELICOIL 4 HOLES EA. END 8 HOLES TOTAL AS
ENLARGED DETAIL SCALE ~ 2/1
CALCULATED DIMS. TO SHARP CORNERS OF 60° CONE WITH .2815 D. BASE
GS ARE OPTIONAL ECT ENGINEER IF BUSHINGS NOT USED 60 ±.0005 D.
.245 ±.001
#8-32 UNC BOTT AT ASS'Y OF BOTH #18 (.1695) DRILL .172 DEEP C'BOR FOR #8 HEX. SOC 22 HOLES AS S
.1160 D. ±.0005
.154 D. ±.001
BUSHING (8 REQ'D) ~ 2/1
E AS SHOWN
PIECE NO
NOMENCLATURE
NO REQ D
NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER, COLORADO, 80302
11 STUB TUNER
FOR 55 - 65 GHz, WR 15 (RG - 98/U)
MODEL
TYPE
SCALE 1/1
DIMENSIONS IN INCHES (Unless otherwise specified)
TOLERANCES (Unless otherwise specified)
DECIMALS ±.005
FRACTIONS ±.015
ANGLES ±½°
DO NOT SCALE THIS PRINT
DRAFTSMAN Victor Lecinski
CHECKER
PROJECT ENGR BILL C. YATES
PROJECT ENGR M.P. WEIDMAN
SUBMITTED BY
CHIEF SEC
EXAMINED BY
CHIEF ENGINEER
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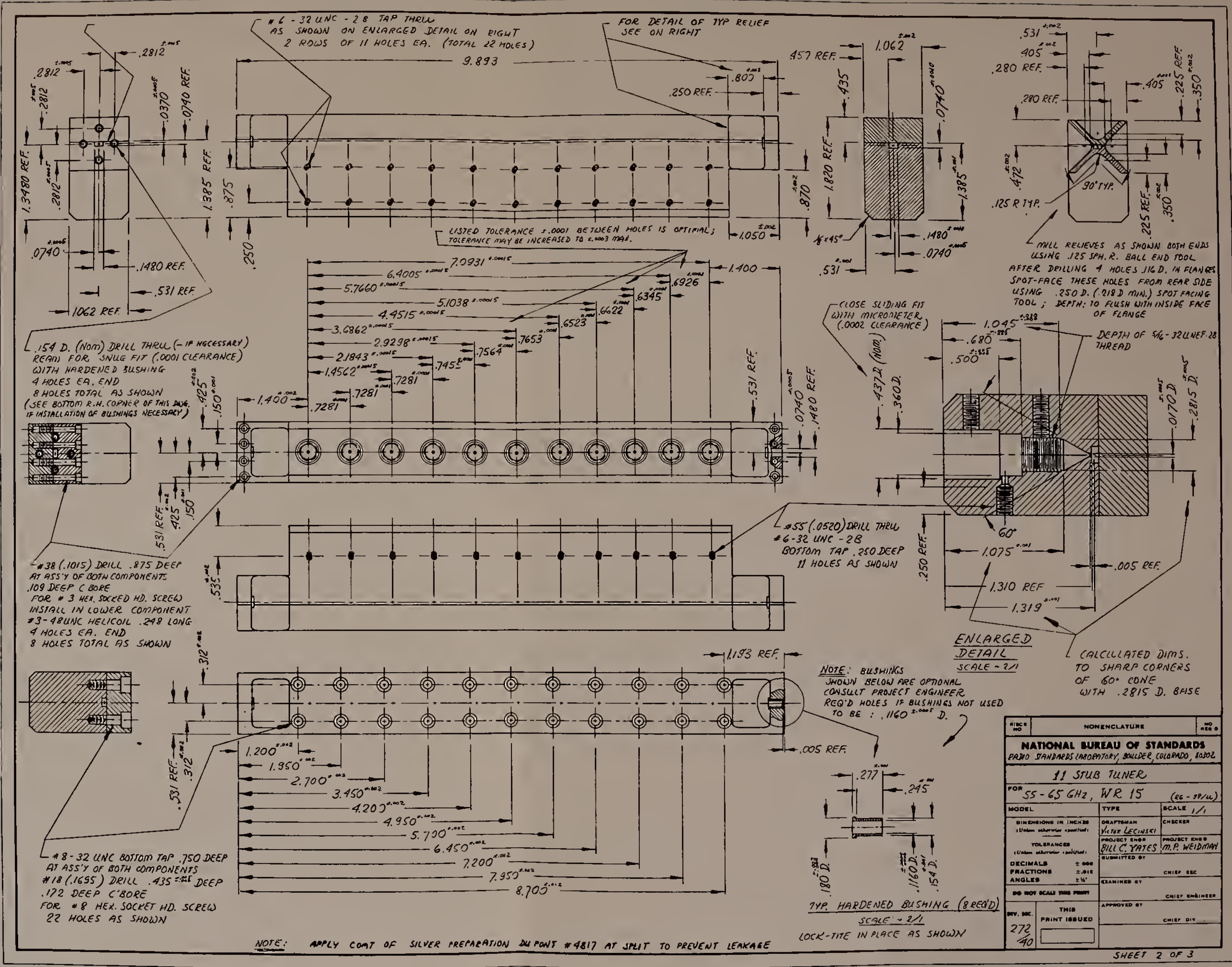
Figure 22(b


#6-32 UNC-28 TAP THRU AS SHOWN ON ENLARGED DETAIL ON RIGHT 2 ROWS OF 11 HOLES EA. (TOTAL 22 HOLES)
FOR DETAIL OF TYP RELIEF SEE ON RIGHT
9.893
LISTED TOLERANCE ±.0001 BETWEEN HOLES IS OPTIMAL; TOLERANCE MAY BE INCREASED TO ±.0003 MAX.
MILL RELIEVES AS SHOWN BOTH ENDS USING .125 SPH. R. BALL END TOOL
AFTER DRILLING 4 HOLES JIG D. IN FLANGES SPOT-FACE THESE HOLES FROM REAR SIDE USING .250 D. (.218 D MIN.) SPOT FACING TOOL; DEPTH: TO FLUSH WITH INSIDE FACE OF FLANGE
90° TYP.
.125 R TYP.
CLOSE SLIDING FIT WITH MICROMETER (.0002 CLEARANCE)
DEPTH OF 5/16-32UNEF-2B THREAD
.154 D. (Nom) DRILL THRU (- IF NECESSARY) REAM FOR SNUG FIT (.0001 CLEARANCE) WITH HARDENED BUSHING 4 HOLES EA. END 8 HOLES TOTAL AS SHOWN (SEE BOTTOM R.H. CORNER OF THIS DWG. IF INSTALLATION OF BUSHINGS NECESSARY)
#38 (.1015) DRILL .875 DEEP AT ASS'Y OF BOTH COMPONENTS .109 DEEP C BORE FOR #3 HEX. SOCKET HD. SCREW INSTALL IN LOWER COMPONENT #3-48UNC HELICOIL .248 LONG 4 HOLES EA. END 8 HOLES TOTAL AS SHOWN
#55 (.0520) DRILL THRU #6-32 UNC-2B BOTTOM TAP .250 DEEP 11 HOLES AS SHOWN
60°
ENLARGED DETAIL SCALE ~ 2/1
CALCULATED DIMS. TO SHARP CORNERS OF 60° CONE WITH .2815 D. BASE
NOTE: BUSHINGS SHOWN BELOW ARE OPTIONAL CONSULT PROJECT ENGINEER REQ'D HOLES IF BUSHINGS NOT USED TO BE: .1160 ±.0005 D.
#8-32 UNC BOTTOM TAP .750 DEEP AT ASS'Y OF BOTH COMPONENTS #18 (.1695) DRILL .435 DEEP .172 DEEP C'BORE FOR #8 HEX. SOCKET HD. SCREW 22 HOLES AS SHOWN
TYP. HARDENED BUSHING (8 REQ'D) SCALE ~ 2/1
LOCK-TITE IN PLACE AS SHOWN
NOTE: APPLY COAT OF SILVER PREPARATION DU PONT #4817 AT SPLIT TO PREVENT LEAKAGE
NOMENCLATURE
NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER, COLORADO, 80302
11 STUB TUNER
FOR 55-65 GHz, WR 15 (RG-98/u)
MODEL
TYPE
SCALE 1/1
DIMENSIONS IN INCHES (Unless otherwise specified)
TOLERANCES (Unless otherwise specified)
DECIMALS
FRACTIONS ±.010
ANGLES ±½°
DO NOT SCALE THIS PRINT
DRAFTSMAN Victor LECINSKI
CHECKER
PROJECT ENGR BILL C. YATES
PROJECT ENGR M.P. WEIDMAN
SUBMITTED BY
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EXAMINED BY
CHIEF ENGINEER
APPROVED BY
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Figure 22(b).

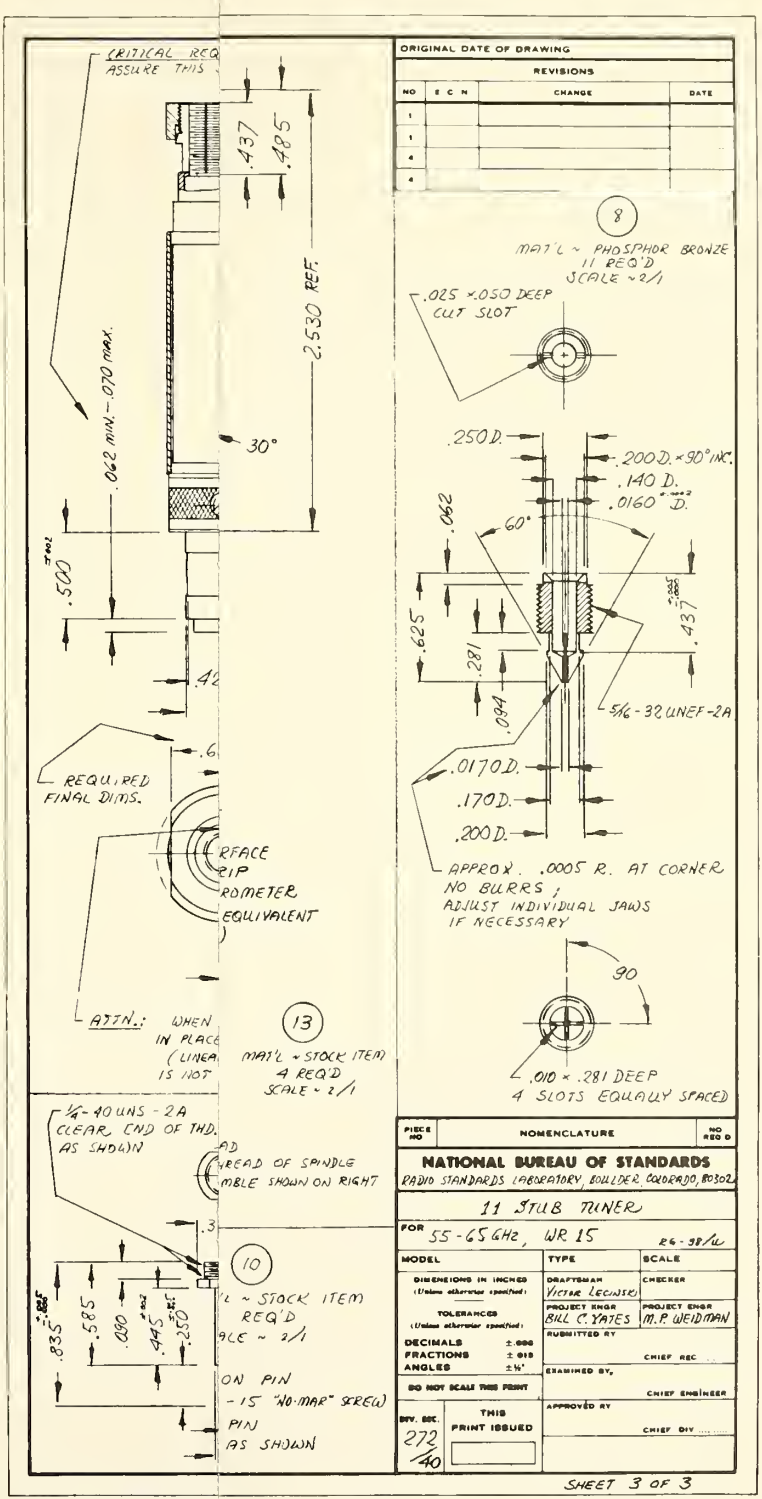
CRITICAL REQ
ASSURE THIS
.437
.485
2.530 REF.
.062 MIN. - .070 MAX.
30°
.500 ±.002
.42
.6
REQUIRED FINAL DIMS.
RFACE
RIP
ROMETER
EQUIVALENT
ATTN.: WHEN
IN PLACE
(LINEA
IS NOT
13
MAT'L ~ STOCK ITEM
4 REQ'D
SCALE ~ 2/1
ORIGINAL DATE OF DRAWING
REVISIONS
NO
E C N
CHANGE
DATE
8
MAT'L ~ PHOSPHOR BRONZE
11 REQ'D
SCALE ~ 2/1
.025 × .050 DEEP CUT SLOT
.250 D.
.200 D. × 90° INC.
.140 D.
.0160 +.0002 D.
.062
60°
.625
.281
.094
.437 +.005 -.000
5/16 - 32 UNEF - 2A
.0170 D.
.170 D.
.200 D.
APPROX. .0005 R. AT CORNER
NO BURRS;
ADJUST INDIVIDUAL JAWS
IF NECESSARY
90
.010 × .281 DEEP
4 SLOTS EQUALLY SPACED
1/4 - 40 UNS - 2A
CLEAR END OF THD.
AS SHOWN
AD
READ OF SPINDLE
MBLE SHOWN ON RIGHT
.3
10
.835 +.005 -.000
.585
.090
.445 ±.002
.250 +.005 -.000
L ~ STOCK ITEM
REQ'D
ALE ~ 2/1
ON PIN
-15 "NO-MAR" SCREW
PIN
AS SHOWN
PIECE NO
NOMENCLATURE
NO REQ'D
NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER, COLORADO, 80302
11 STUB TUNER
FOR 55-65 GHz, WR 15
RG-98/U
MODEL
TYPE
SCALE
DIMENSIONS IN INCHES (Unless otherwise specified)
TOLERANCES (Unless otherwise specified)
DECIMALS ±.005
FRACTIONS ±.015
ANGLES ±1/2°
DO NOT SCALE THIS PRINT
DRAFTSMAN Victor Lecinski
CHECKER
PROJECT ENGR BILL C. YATES
PROJECT ENGR M.P. WEIDMAN
SUBMITTED BY
CHIEF REC
EXAMINED BY,
CHIEF ENGINEER
APPROVED BY
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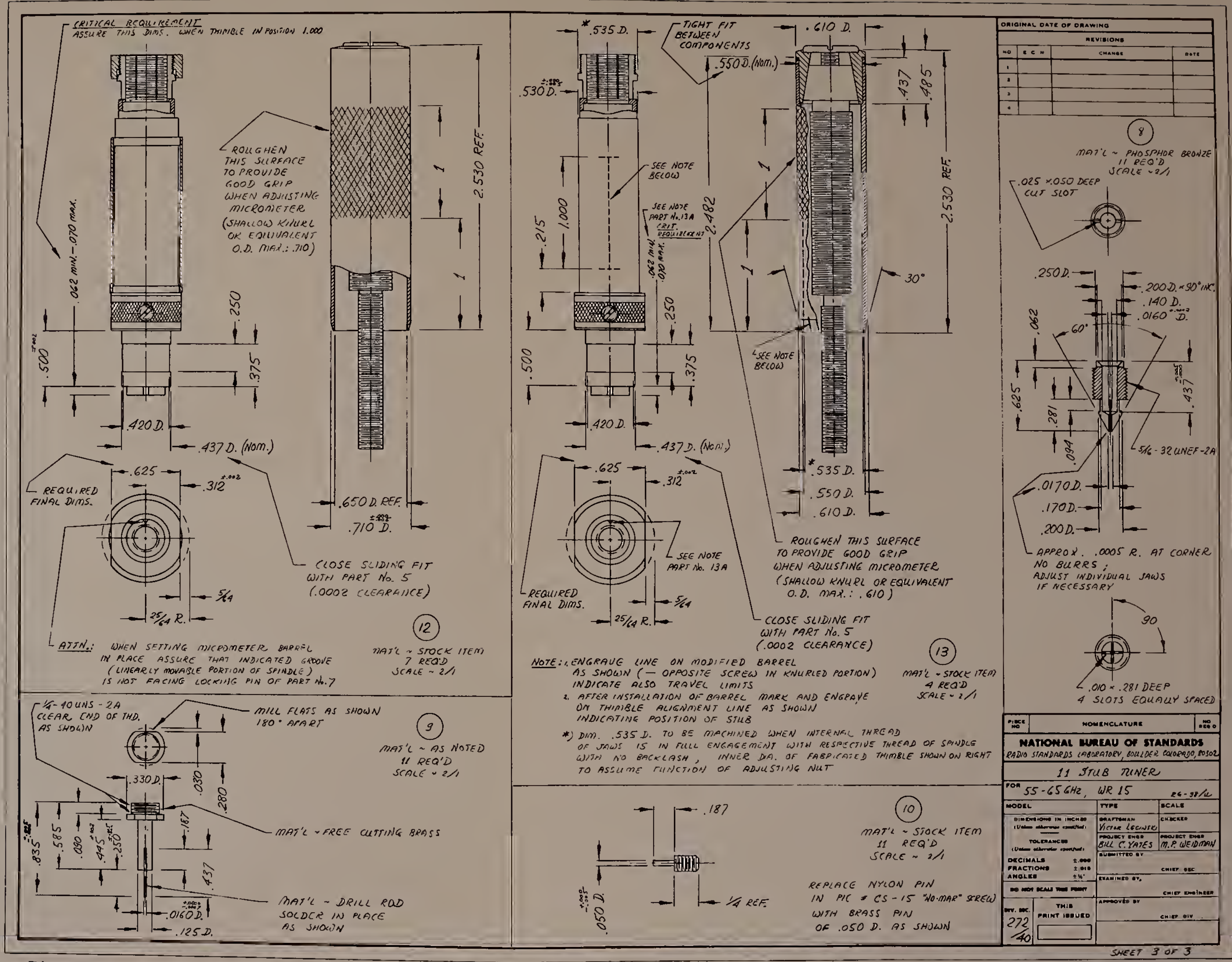
Figure 22(c


CRITICAL REQUIREMENT
ASSURE THIS DIMS. WHEN THIMBLE IN POSITION 1.000
.062 MIN. - .070 MAX.
ROUGHEN THIS SURFACE TO PROVIDE GOOD GRIP WHEN ADJUSTING MICROMETER (SHALLOW KNURL OR EQUIVALENT O.D. MAX.: .710)
2.530 REF.
.250
.500
.375
.420 D.
.437 D. (Nom.)
.625
.312
REQUIRED FINAL DIMS.
.650 D. REF.
.710 D.
CLOSE SLIDING FIT WITH PART No. 5 (.0002 CLEARANCE)
5/64
25/64 R.
ATTN.: WHEN SETTING MICROMETER BARREL IN PLACE ASSURE THAT INDICATED GROOVE (LINEARLY MOVABLE PORTION OF SPINDLE) IS NOT FACING LOCKING PIN OF PART No. 7
12
MAT'L ~ STOCK ITEM
7 REQ'D
SCALE ~ 2/1
*.535 D.
.530 D.
TIGHT FIT BETWEEN COMPONENTS
.550 D. (Nom.)
.610 D.
.437
.485
SEE NOTE BELOW
SEE NOTE PART No. 13A CRIT. REQUIREMENT
.215
1.000
2.482
.062 MIN. .070 MAX.
30°
SEE NOTE BELOW
*.535 D.
.550 D.
.610 D.
SEE NOTE PART No. 13A
ROUGHEN THIS SURFACE TO PROVIDE GOOD GRIP WHEN ADJUSTING MICROMETER (SHALLOW KNURL OR EQUIVALENT O.D. MAX.: .610)
CLOSE SLIDING FIT WITH PART No. 5 (.0002 CLEARANCE)
13
MAT'L ~ STOCK ITEM
4 REQ'D
SCALE ~ 2/1
NOTE: 1. ENGRAVE LINE ON MODIFIED BARREL AS SHOWN (— OPPOSITE SCREW IN KNURLED PORTION) INDICATE ALSO TRAVEL LIMITS
2. AFTER INSTALLATION OF BARREL MARK AND ENGRAVE ON THIMBLE ALIGNMENT LINE AS SHOWN INDICATING POSITION OF STUB
*) DIM. .535 D. TO BE MACHINED WHEN INTERNAL THREAD OF JAWS IS IN FULL ENGAGEMENT WITH RESPECTIVE THREAD OF SPINDLE WITH NO BACKLASH, INNER DIA. OF FABRICATED THIMBLE SHOWN ON RIGHT TO ASSUME FUNCTION OF ADJUSTING NUT
8
MAT'L ~ PHOSPHOR BRONZE
11 REQ'D
SCALE ~ 2/1
.025 × .050 DEEP CUT SLOT
.250 D.
.200 D. × 90° INC.
.140 D.
.0160 D.
.062
60°
.625
.281
.094
.437
5/16 - 32 UNEF-2A
.0170 D.
.170 D.
.200 D.
APPROX. .0005 R. AT CORNER. NO BURRS; ADJUST INDIVIDUAL JAWS IF NECESSARY
90
.010 × .281 DEEP
4 SLOTS EQUALLY SPACED
1/4 - 40 UNS - 2A CLEAR END OF THD. AS SHOWN
MILL FLATS AS SHOWN 180° APART
9
MAT'L ~ AS NOTED
11 REQ'D
SCALE ~ 2/1
.330 D.
.030
.280
.835
.585
.050
.445
.250
.167
.437
MAT'L ~ FREE CUTTING BRASS
MAT'L ~ DRILL ROD SOLDER IN PLACE AS SHOWN
.0160 D.
.125 D.
.187
.050 D.
1/4 REF.
10
MAT'L ~ STOCK ITEM
11 REQ'D
SCALE ~ 2/1
REPLACE NYLON PIN IN PIC # CS-15 "NO-MAR" SCREW WITH BRASS PIN OF .050 D. AS SHOWN
ORIGINAL DATE OF DRAWING
REVISIONS
NO
E C N
CHANGE
DATE
PIECE NO
NOMENCLATURE
NO REQ'D
NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER COLORADO, 80302
11 STUB TUNER
FOR 55-65 GHz, WR 15
26-38/L
MODEL
TYPE
SCALE
DIMENSIONS IN INCHES (Unless otherwise specified)
TOLERANCES (Unless otherwise specified)
DECIMALS ±.005
FRACTIONS ±.010
ANGLES ±½°
DO NOT SCALE THIS PRINT
DRAFTSMAN Victor Lecinski
CHECKER
PROJECT ENGR BILL C. YATES
PROJECT ENGR M.P. WEIDMAN
SUBMITTED BY
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EXAMINED BY
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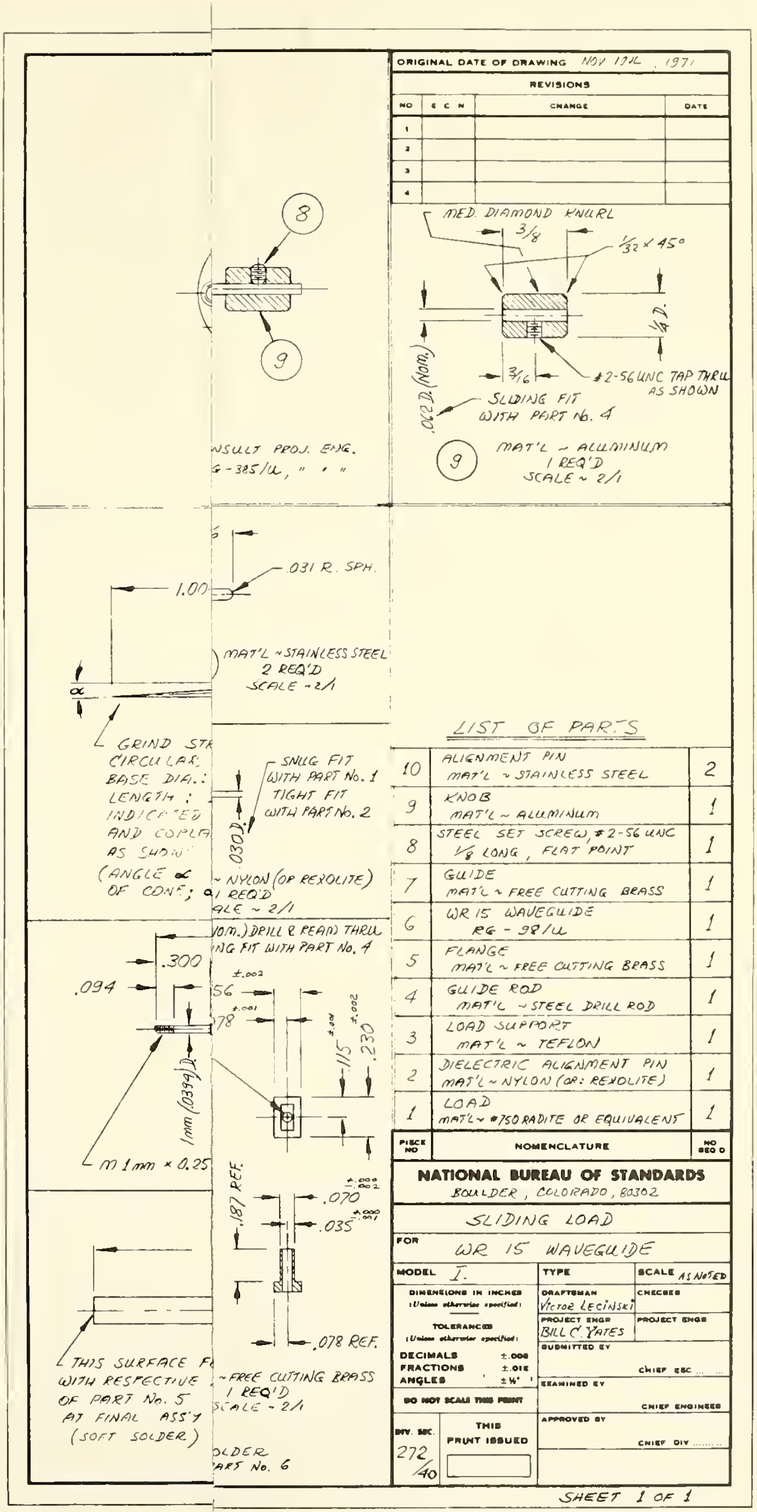
Figure 22(c).

APPENDIX E

Machine drawing for sliding load
for WR15 waveguide.
Figure 23



ORIGINAL DATE OF DRAWING NOV 17th, 1971

REVISIONS			
NO	E C N	CHANGE	DATE
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4			

LIST OF PARTS

PIECE NO	NOMENCLATURE	NO REQ D
10	ALIGNMENT PIN MAT'L ~ STAINLESS STEEL	2
9	KNOB MAT'L ~ ALUMINUM	1
8	STEEL SET SCREW, #2-56 UNC 1/8 LONG, FLAT POINT	1
7	GUIDE MAT'L ~ FREE CUTTING BRASS	1
6	WR 15 WAVEGUIDE RG - 98/U	1
5	FLANGE MAT'L ~ FREE CUTTING BRASS	1
4	GUIDE ROD MAT'L ~ STEEL DRILL ROD	1
3	LOAD SUPPORT MAT'L ~ TEFLON	1
2	DIELECTRIC ALIGNMENT PIN MAT'L ~ NYLON (OR: REXOLITE)	1
1	LOAD MAT'L ~ #750 RADITE OR EQUIVALENT	1

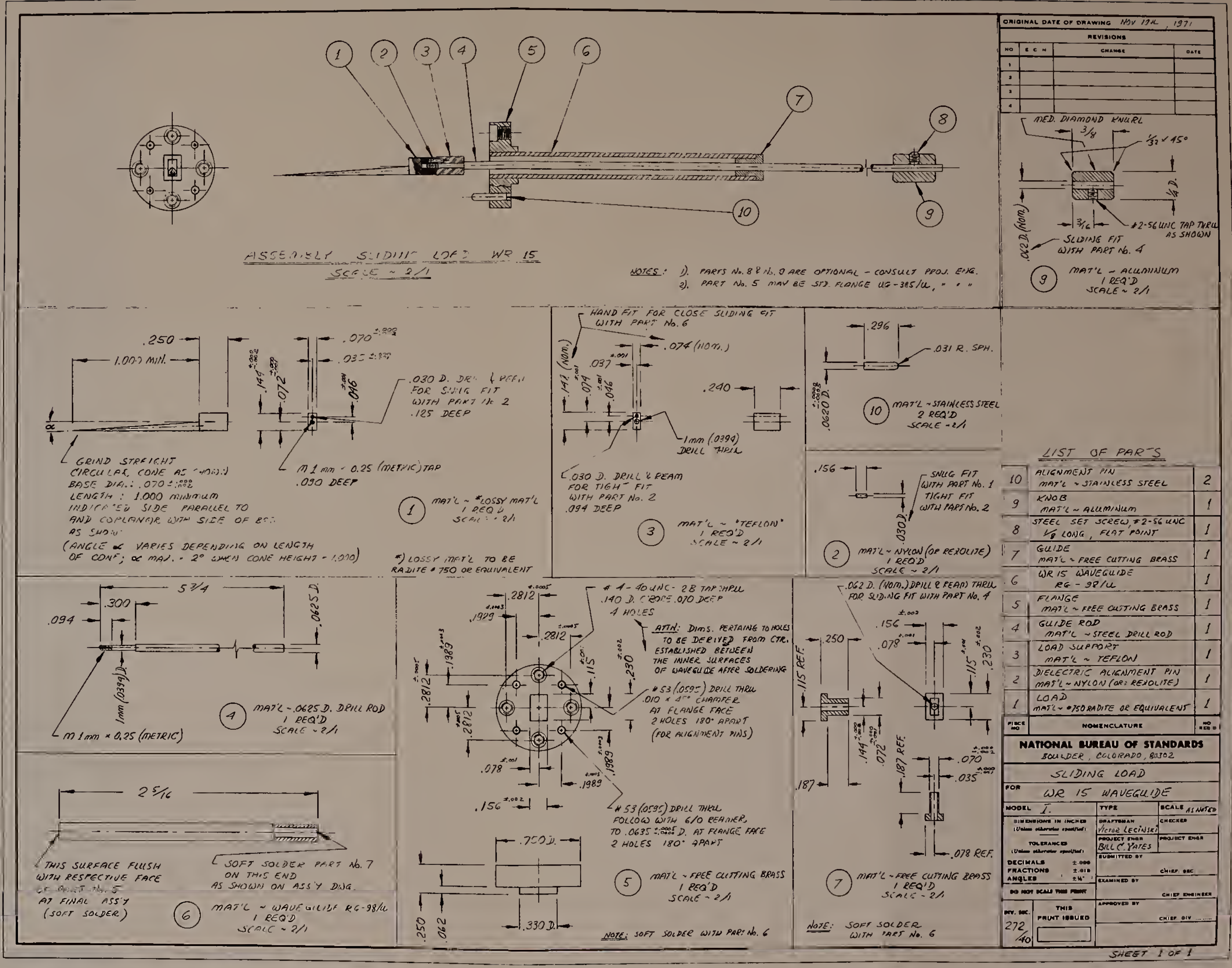
NATIONAL BUREAU OF STANDARDS
BOULDER, COLORADO, 80302

SLIDING LOAD
FOR WR 15 WAVEGUIDE

MODEL I.	TYPE	SCALE AS NOTED
DIMENSIONS IN INCHES (Unless otherwise specified)	DRAFTSMAN Victor Lecinski	CHECKED
TOLERANCES (Unless otherwise specified) DECIMALS ±.005 FRACTIONS ±.015 ANGLES ±½°	PROJECT ENGR BILL C. YATES	PROJECT ENGR
	SUBMITTED BY	CHIEF SEC ......
DO NOT SCALE THIS PRINT	EXAMINED BY	CHIEF ENGINEER
DIV. SEC. 272/40 — THIS PRINT ISSUED ☐	APPROVED BY	CHIEF DIV ....

SHEET 1 OF 1

Figure 23.



LIST OF PARTS

PIECE NO	NOMENCLATURE	NO REQ'D
10	ALIGNMENT PIN MAT'L ~ STAINLESS STEEL	2
9	KNOB MAT'L ~ ALUMINUM	1
8	STEEL SET SCREW, #2-56 UNC 1/8 LONG, FLAT POINT	1
7	GUIDE MAT'L ~ FREE CUTTING BRASS	1
6	WR 15 WAVEGUIDE RG - 98/U	1
5	FLANGE MAT'L ~ FREE CUTTING BRASS	1
4	GUIDE ROD MAT'L ~ STEEL DRILL ROD	1
3	LOAD SUPPORT MAT'L ~ TEFLON	1
2	DIELECTRIC ALIGNMENT PIN MAT'L ~ NYLON (OR: REXOLITE)	1
1	LOAD MAT'L ~ #750 RADITE OR EQUIVALENT	1

NATIONAL BUREAU OF STANDARDS
BOULDER, COLORADO, 80302

SLIDING LOAD
FOR WR 15 WAVEGUIDE

MODEL I.	TYPE	SCALE AS NOTED
DIMENSIONS IN INCHES (Unless otherwise specified)	DRAFTSMAN Victor Lecinski	CHECKER
TOLERANCES (Unless otherwise specified) DECIMALS ±.000 FRACTIONS ±.015 ANGLES ±½°	PROJECT ENGR BILL C. YATES	PROJECT ENGR
	SUBMITTED BY	CHIEF SEC
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INV. SEC. 272/40 — THIS PRINT ISSUED	APPROVED BY	CHIEF DIV

SHEET 1 OF 1

Figure 23.

APPENDIX F

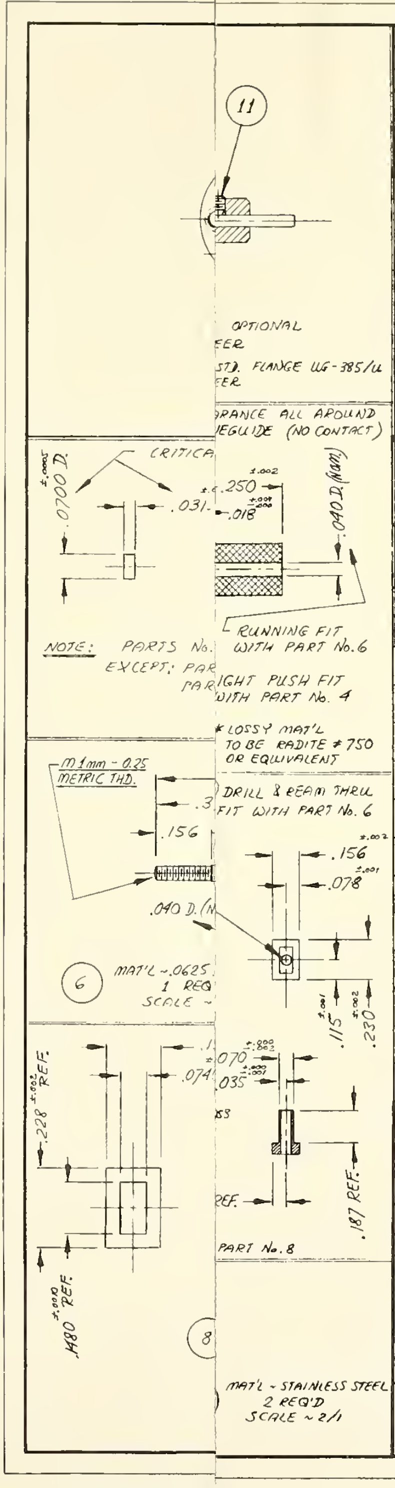
Machine drawing for sliding dumbell short for WR15 waveguide.

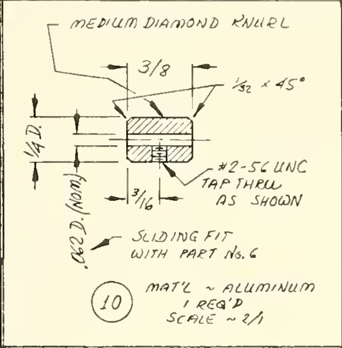
Figure 24

ORIGINAL DATE OF DRAWING

REVISIONS

NO	E C N	CHANGE	DATE
1			
2			
3			
4			





LIST OF PARTS

PIECE NO	NOMENCLATURE	NO REQ'D
11	STEEL SET SCREW, #2-56 UNC 1/8 LONG, FLAT POINT	1
10	KNOB MAT'L ~ ALUMINUM	1
9	GUIDE MAT'L ~ FREE CUTTING BRASS	1
8	WR 15 WAVEGUIDE MAT'L ~ RG-98/U WAVEGUIDE	1
7	FLANGE MAT'L ~ FREE CUTTING BRASS	1
6	GUIDE ROD MAT'L ~ STEEL DRILL ROD	1
5	LOSSY MAT'L GUIDE MAT'L ~ RADITE # 750 OR EQUIVALENT	1
4	DUMBBELL SUPPORT MAT'L ~ REXOLITE	1
3	DIELECTRIC SPACER MAT'L ~ REXOLITE	3
2	DUMBBELL COMPONENT MAT'L ~ FREE CUTTING BRASS	3
1	ALIGNMENT PIN MAT'L ~ STAINLESS STEEL	2

NATIONAL BUREAU OF STANDARDS
BOULDER, COLORADO, 80302

SLIDING DUMBBELL SHORT

FOR WR 15

MODEL I.	TYPE	SCALE AS NOTED
DIMENSIONS IN INCHES (Unless otherwise specified)	DRAFTSMAN VICTOR LECINSKI	CHECKED
TOLERANCES (Unless otherwise specified)	PROJECT ENGR BILL C. YATES	PROJECT ENGR
DECIMALS ±.005 FRACTIONS ±.015 ANGLES ±½°	SUBMITTED BY CHIEF SEC.	
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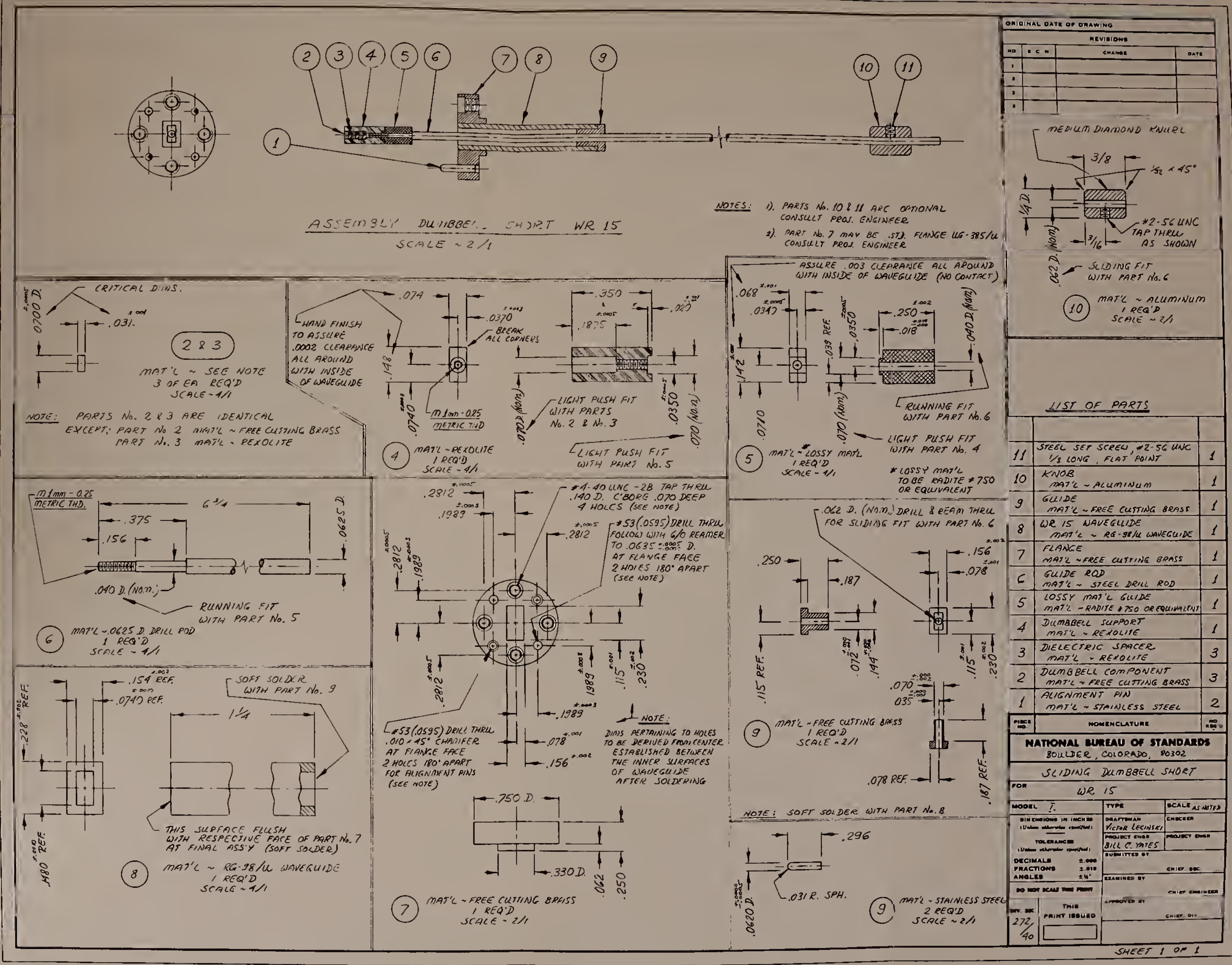
DIV. SEC. 272/40 — THIS PRINT ISSUED	APPROVED BY CHIEF DIV	

SHEET 1 OF 1

Figure 24



LIST OF PARTS

PIECE NO.	NOMENCLATURE	NO. REQ'D
11	STEEL SET SCREW, #2-56 UNC 1/8 LONG, FLAT POINT	1
10	KNOB MAT'L ~ ALUMINUM	1
9	GUIDE MAT'L ~ FREE CUTTING BRASS	1
8	WR 15 WAVEGUIDE MAT'L ~ RG-98/U WAVEGUIDE	1
7	FLANGE MAT'L ~ FREE CUTTING BRASS	1
6	GUIDE ROD MAT'L ~ STEEL DRILL ROD	1
5	LOSSY MAT'L GUIDE MAT'L ~ RADITE #750 OR EQUIVALENT	1
4	DUMBBELL SUPPORT MAT'L ~ REXOLITE	1
3	DIELECTRIC SPACER MAT'L ~ REXOLITE	3
2	DUMBBELL COMPONENT MAT'L ~ FREE CUTTING BRASS	3
1	ALIGNMENT PIN MAT'L ~ STAINLESS STEEL	2

NATIONAL BUREAU OF STANDARDS
BOULDER, COLORADO, 80302

SLIDING DUMBBELL SHORT
FOR WR 15
MODEL I.
TYPE
SCALE AS NOTED
DIMENSIONS IN INCHES (Unless otherwise specified)
TOLERANCES (Unless otherwise specified)
DECIMALS ±.000
FRACTIONS ±.010
ANGLES ±½°
DO NOT SCALE THIS PRINT
DRAFTSMAN Victor Lecinski
CHECKER
PROJECT ENGR Bill C. Yates
PROJECT ENGR
SUBMITTED BY CHIEF, SEC.
EXAMINED BY CHIEF ENGINEER
APPROVED BY CHIEF, DIV.
DIV. SEC. 272/40
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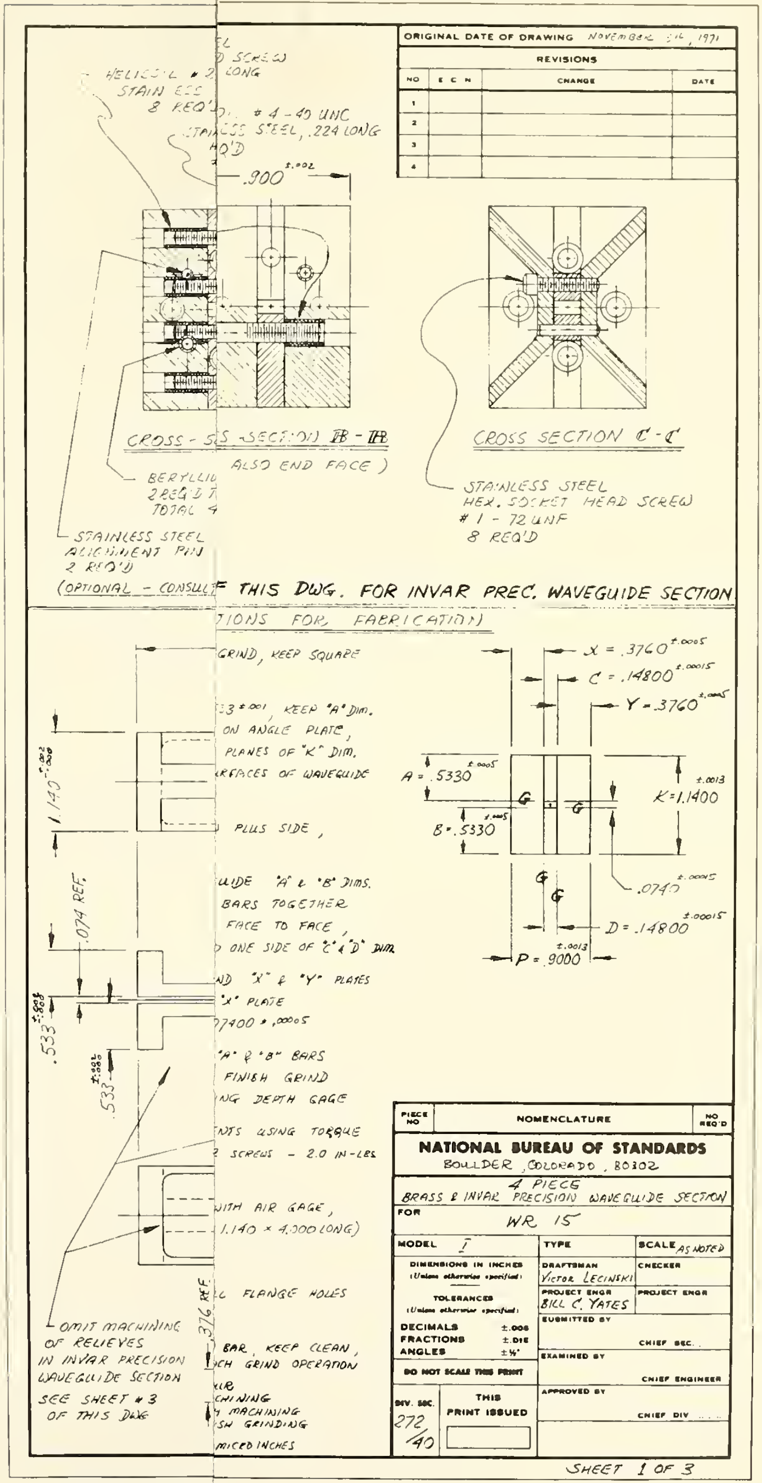
SHEET 1 OF 1

Figure 24.

APPENDIX G

Machine drawing for four piece brass and invar precision waveguide section for WR15.

Figures 25(a), 25(b), 25(c).


ORIGINAL DATE OF DRAWING NOVEMBER 5th, 1971
REVISIONS
NO
E C N
CHANGE
DATE
1
2
3
4
EL
D SCREW
HELICOIL # 2 LONG
STAINLESS
8 REQ'D
4 - 40 UNC
STAINLESS STEEL, .224 LONG
RQ'D
.900 ±.002
CROSS - SECTION B - B
ALSO END FACE)
CROSS SECTION C - C
BERYLLIU
2 REQ'D
TOTAL 4
STAINLESS STEEL
HEX. SOCKET HEAD SCREW
1 - 72 UNF
8 REQ'D
STAINLESS STEEL
ALIGNMENT PIN
2 REQ'D
(OPTIONAL - CONSULT
F THIS DWG. FOR INVAR PREC. WAVEGUIDE SECTION
TIONS FOR FABRICATION
GRIND, KEEP SQUARE
33 ±.001, KEEP "A" DIM.
ON ANGLE PLATE,
PLANES OF "K" DIM.
RFACES OF WAVEGUIDE
PLUS SIDE,
UIDE "A" & "B" DIMS.
BARS TOGETHER
FACE TO FACE,
ONE SIDE OF "C" & "D" DIM
ND "X" & "Y" PLATES
"X" PLATE
07400 ±.00005
"A" & "B" BARS
FINISH GRIND
NG DEPTH GAGE
NTS USING TORQUE
SCREWS - 2.0 IN-LBS
WITH AIR GAGE,
1.140 × 4.000 LONG)
L FLANGE HOLES
BAR, KEEP CLEAN,
CH GRIND OPERATION
UR
CHINING
MACHINING
SH GRINDING
MICRO INCHES
1.140 +.002 -.000
.074 REF.
.533 +.002 -.000
.533 +.002 -.000
.376 REF.
OMIT MACHINING
OF RELIEVES
IN INVAR PRECISION
WAVEGUIDE SECTION
SEE SHEET # 3
OF THIS DWG
X = .3760 ±.0005
C = .14800 ±.00015
Y = .3760 ±.0005
A = .5330 ±.0005
B = .5330 ±.0005
K = 1.1400 ±.0013
G
G
G
G
.0740 ±.00015
D = .14800 ±.00015
P = .9000 ±.0013
PIECE NO
NOMENCLATURE
NO REQ'D
NATIONAL BUREAU OF STANDARDS
BOULDER, COLORADO, 80302
4 PIECE
BRASS & INVAR PRECISION WAVEGUIDE SECTION
FOR WR 15
MODEL I
TYPE
SCALE AS NOTED
DIMENSIONS IN INCHES (Unless otherwise specified)
TOLERANCES (Unless otherwise specified)
DECIMALS ±.005
FRACTIONS ±.015
ANGLES ±½°
DO NOT SCALE THIS PRINT
DRAFTSMAN VICTOR LECINSKI
CHECKER
PROJECT ENGR BILL C. YATES
PROJECT ENGR
SUBMITTED BY
CHIEF SEC.
EXAMINED BY
CHIEF ENGINEER
APPROVED BY
CHIEF DIV.
DIV. SEC. 272/40
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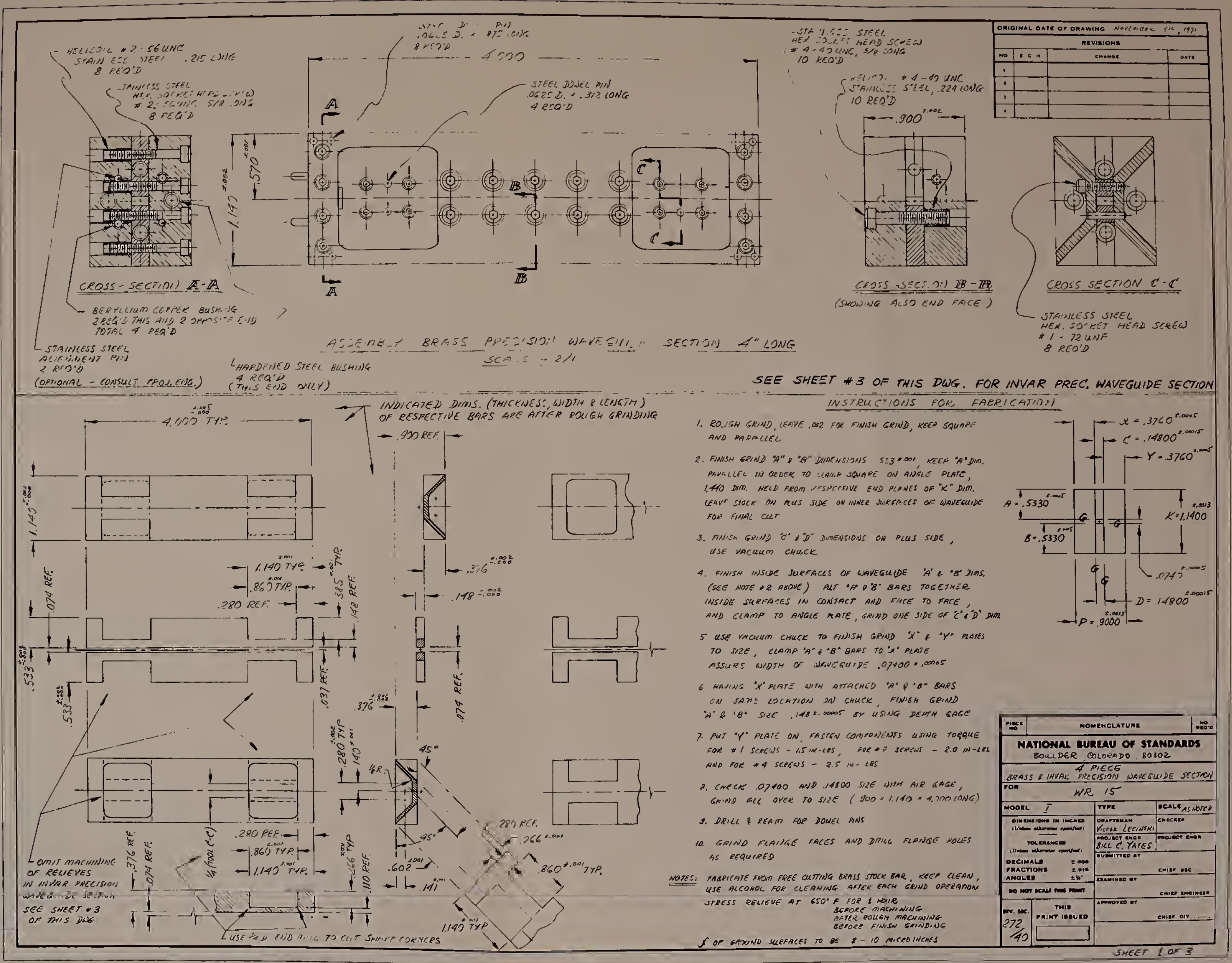
SHEET 1 OF 3

Figure 25(



ORIGINAL DATE OF DRAWING	November 5th, 1971		
REVISIONS			
NO	E C N	CHANGE	DATE
1			
2			
3			
4			

SEE SHEET #3 OF THIS DWG. FOR INVAR PREC. WAVEGUIDE SECTION

INSTRUCTIONS FOR FABRICATION

1. ROUGH GRIND, LEAVE .002 FOR FINISH GRIND, KEEP SQUARE AND PARALLEL
2. FINISH GRIND "A" & "B" DIMENSIONS .533 ±.001, KEEP "A" DIM. PARALLEL IN ORDER TO CLAMP SQUARE ON ANGLE PLATE, 1.140 DIM. HELD FROM RESPECTIVE END PLANES OF "K" DIM. LEAVE STOCK ON PLUS SIDE ON INNER SURFACES OF WAVEGUIDE FOR FINAL CUT
3. FINISH GRIND "C" & "D" DIMENSIONS ON PLUS SIDE, USE VACUUM CHUCK
4. FINISH INSIDE SURFACES OF WAVEGUIDE "A" & "B" DIMS. (SEE NOTE #2 ABOVE) PUT "A" & "B" BARS TOGETHER INSIDE SURFACES IN CONTACT AND FACE TO FACE, AND CLAMP TO ANGLE PLATE, GRIND ONE SIDE OF "C" & "D" DIM.
5. USE VACUUM CHUCK TO FINISH GRIND "X" & "Y" PLATES TO SIZE, CLAMP "A" & "B" BARS TO "X" PLATE ASSURE WIDTH OF WAVEGUIDE .07400 ±.00005
6. HAVING "X" PLATE WITH ATTACHED "A" & "B" BARS ON SAME LOCATION ON CHUCK, FINISH GRIND "A" & "B" SIZE .148 ±.00005 BY USING DEPTH GAGE
7. PUT "Y" PLATE ON, FASTEN COMPONENTS USING TORQUE FOR #1 SCREWS - 1.5 IN-LBS, FOR #2 SCREWS - 2.0 IN-LBS AND FOR #4 SCREWS - 2.5 IN-LBS
8. CHECK .07400 AND .14800 SIZE WITH AIR GAGE, GRIND ALL OVER TO SIZE (.900 × 1.140 × 4.000 LONG)
9. DRILL & REAM FOR DOWEL PINS
10. GRIND FLANGE FACES AND DRILL FLANGE HOLES AS REQUIRED

NOTES: FABRICATE FROM FREE CUTTING BRASS STOCK BAR, KEEP CLEAN, USE ALCOHOL FOR CLEANING AFTER EACH GRIND OPERATION
STRESS RELIEVE AT 650° F FOR 1 HOUR
BEFORE MACHINING
AFTER ROUGH MACHINING
BEFORE FINISH GRINDING
∫ OF GROUND SURFACES TO BE 8 - 10 MICROINCHES

PIECE NO	NOMENCLATURE		NO REQ'D
NATIONAL BUREAU OF STANDARDS BOULDER, COLORADO, 80302			
4 PIECE BRASS & INVAR PRECISION WAVEGUIDE SECTION			
FOR WR 15			
MODEL I	TYPE	SCALE AS NOTED	
DIMENSIONS IN INCHES (Unless otherwise specified) TOLERANCES (Unless otherwise specified) DECIMALS ±.000 FRACTIONS ±.010 ANGLES ±½°	DRAFTSMAN Victor Lecinski	CHECKER	
	PROJECT ENGR Bill C. Yates	PROJECT ENGR	
	SUBMITTED BY CHIEF SEC		
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SHEET 1 OF 3

Figure 25(a).

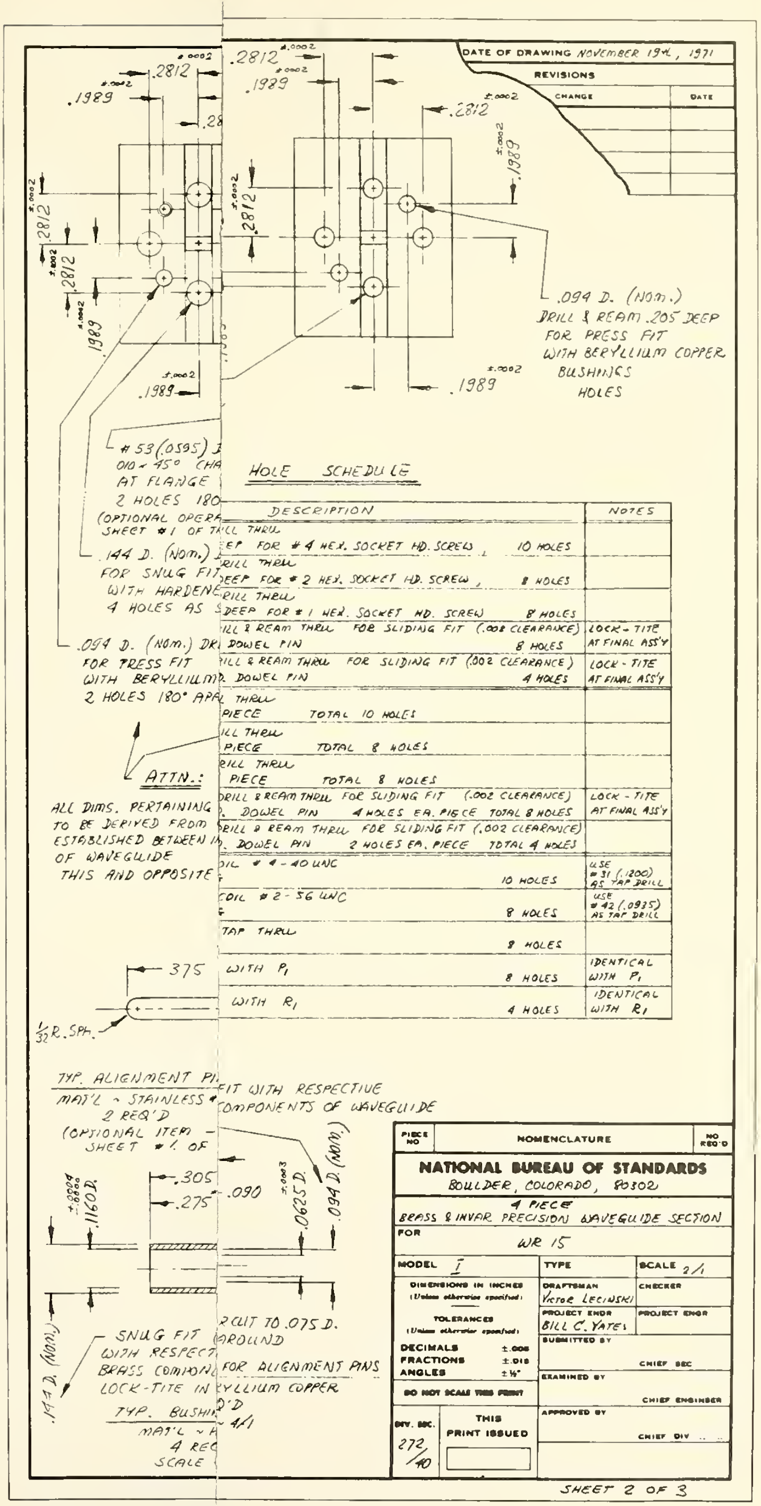
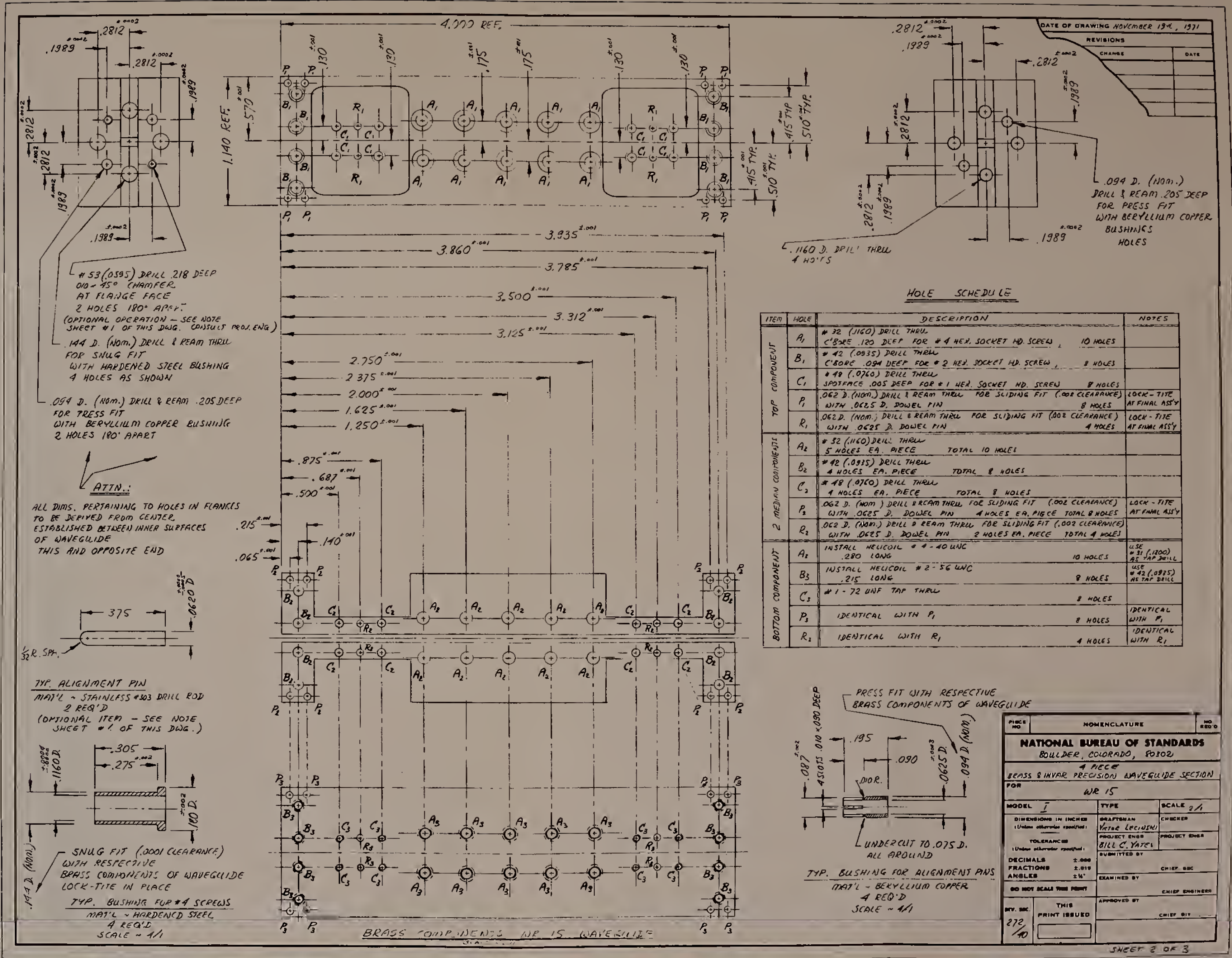

DATE OF DRAWING NOVEMBER 19th, 1971
REVISIONS
CHANGE
DATE
.2812
.1989
±.0002
.2812
.094 D. (Nom.)
DRILL & REAM .205 DEEP
FOR PRESS FIT
WITH BERYLLIUM COPPER
BUSHINGS
HOLES
53 (.0595)
010 × 45° CHA
AT FLANGE
2 HOLES 180
(OPTIONAL OPERA
SHEET #1 OF TH
.144 D. (Nom.)
FOR SNUG FIT
WITH HARDENE
4 HOLES AS S
.094 D. (Nom.) DR
FOR PRESS FIT
WITH BERYLLIUM
2 HOLES 180° APA
ATTN.:
ALL DIMS. PERTAINING
TO BE DERIVED FROM
ESTABLISHED BETWEEN IN
OF WAVEGUIDE
THIS AND OPPOSITE
HOLE SCHEDULE
DESCRIPTION
NOTES
RILL THRU
EEP FOR #4 HEX. SOCKET HD. SCREW, 10 HOLES
RILL THRU
DEEP FOR #2 HEX. SOCKET HD. SCREW, 8 HOLES
RILL THRU
DEEP FOR #1 HEX. SOCKET HD. SCREW 8 HOLES
ILL & REAM THRU FOR SLIDING FIT (.002 CLEARANCE) DOWEL PIN 8 HOLES
LOCK-TITE AT FINAL ASS'Y
ILL & REAM THRU FOR SLIDING FIT (.002 CLEARANCE) DOWEL PIN 4 HOLES
LOCK-TITE AT FINAL ASS'Y
L THRU PIECE TOTAL 10 HOLES
ILL THRU PIECE TOTAL 8 HOLES
RILL THRU PIECE TOTAL 8 HOLES
DRILL & REAM THRU FOR SLIDING FIT (.002 CLEARANCE) DOWEL PIN 4 HOLES EA. PIECE TOTAL 8 HOLES
LOCK-TITE AT FINAL ASS'Y
RILL & REAM THRU FOR SLIDING FIT (.002 CLEARANCE) DOWEL PIN 2 HOLES EA. PIECE TOTAL 4 HOLES
OIL #4-40 UNC 10 HOLES
USE #31 (.1200) AS TAP DRILL
COIL #2-56 UNC 8 HOLES
USE #42 (.0935) AS TAP DRILL
TAP THRU 8 HOLES
WITH P1 8 HOLES
IDENTICAL WITH P1
WITH R1 4 HOLES
IDENTICAL WITH R1
.375
1/32 R. SPH.
TYP. ALIGNMENT PI
MAT'L ~ STAINLESS
2 REQ'D
(OPTIONAL ITEM –
SHEET #1 OF
FIT WITH RESPECTIVE
COMPONENTS OF WAVEGUIDE
.305
.275
.090
+.0004 −.0000
.1160 D.
±.0003
.0625 D.
.094 D. (Nom.)
.144 D. (Nom.)
SNUG FIT
WITH RESPECT
BRASS COMPON
LOCK-TITE IN
R CUT TO .075 D.
AROUND
FOR ALIGNMENT PINS
YLLIUM COPPER
Q'D
~ 4/1
TYP. BUSHI
MAT'L ~ H
4 REQ
SCALE
PIECE NO
NOMENCLATURE
NO REQ'D
NATIONAL BUREAU OF STANDARDS
BOULDER, COLORADO, 80302
4 PIECE
BRASS & INVAR PRECISION WAVEGUIDE SECTION
FOR
WR 15
MODEL I
TYPE
SCALE 2/1
DIMENSIONS IN INCHES (Unless otherwise specified)
TOLERANCES (Unless otherwise specified)
DECIMALS ±.005
FRACTIONS ±.010
ANGLES ±½°
DO NOT SCALE THIS PRINT
DRAFTSMAN Victor Lecinski
CHECKER
PROJECT ENGR Bill C. Yates
PROJECT ENGR
SUBMITTED BY
CHIEF SEC
EXAMINED BY
CHIEF ENGINEER
APPROVED BY
CHIEF DIV
DIV. SEC. 272/40
THIS PRINT ISSUED
SHEET 2 OF 3

Figure 25(



HOLE SCHEDULE

ITEM	HOLE	DESCRIPTION	NOTES
TOP COMPONENT	A_1	# 32 (.1160) DRILL THRU C'BORE .120 DEEP FOR # 4 HEX. SOCKET HD. SCREW, 10 HOLES	
	B_1	# 42 (.0935) DRILL THRU C'BORE .094 DEEP FOR # 2 HEX. SOCKET HD. SCREW, 8 HOLES	
	C_1	# 48 (.0760) DRILL THRU SPOTFACE .005 DEEP FOR # 1 HEX. SOCKET HD. SCREW 8 HOLES	
	P_1	.062 D. (NOM.) DRILL & REAM THRU FOR SLIDING FIT (.002 CLEARANCE) WITH .0625 D. DOWEL PIN 8 HOLES	LOCK-TITE AT FINAL ASS'Y
	R_1	.062 D. (NOM.) DRILL & REAM THRU FOR SLIDING FIT (.002 CLEARANCE) WITH .0625 D. DOWEL PIN 4 HOLES	LOCK-TITE AT FINAL ASS'Y
2 MEDIAN COMPONENTS	A_2	# 32 (.1160) DRILL THRU 5 HOLES EA. PIECE TOTAL 10 HOLES	
	B_2	# 42 (.0935) DRILL THRU 4 HOLES EA. PIECE TOTAL 8 HOLES	
	C_2	# 48 (.0760) DRILL THRU 4 HOLES EA. PIECE TOTAL 8 HOLES	
	P_2	.062 D. (NOM.) DRILL & REAM THRU FOR SLIDING FIT (.002 CLEARANCE) WITH .0625 D. DOWEL PIN 4 HOLES EA. PIECE TOTAL 8 HOLES	LOCK-TITE AT FINAL ASS'Y
	R_2	.062 D. (NOM.) DRILL & REAM THRU FOR SLIDING FIT (.002 CLEARANCE) WITH .0625 D. DOWEL PIN 2 HOLES EA. PIECE TOTAL 4 HOLES	
BOTTOM COMPONENT	A_3	INSTALL HELICOIL # 4-40 UNC .280 LONG 10 HOLES	USE # 31 (.1200) AS TAP DRILL
	B_3	INSTALL HELICOIL # 2-56 UNC .215 LONG 8 HOLES	USE # 42 (.0935) AS TAP DRILL
	C_3	# 1-72 UNF TAP THRU 8 HOLES	
	P_3	IDENTICAL WITH P_1 8 HOLES	IDENTICAL WITH P_1
	R_3	IDENTICAL WITH R_1 4 HOLES	IDENTICAL WITH R_1

Figure 25(b).

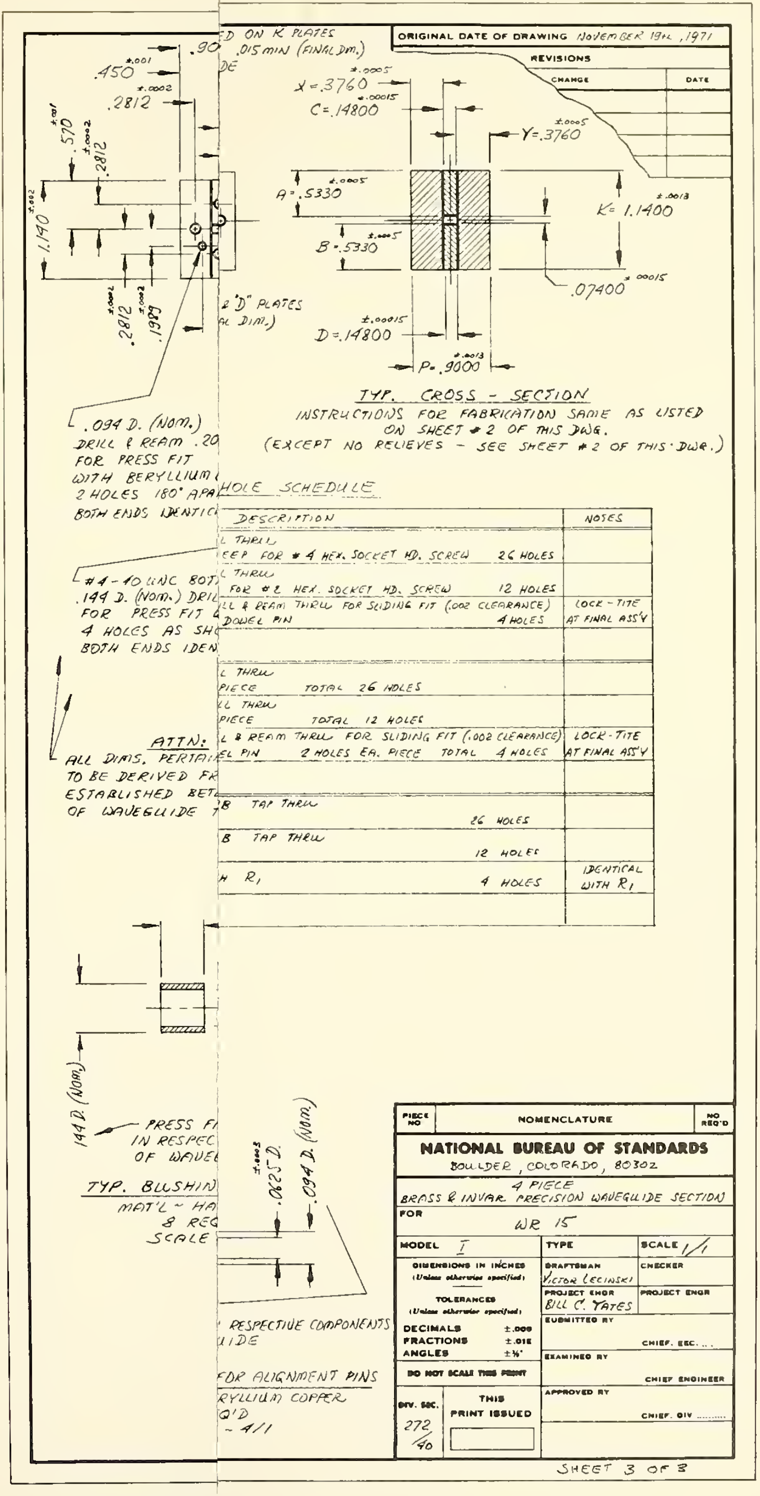
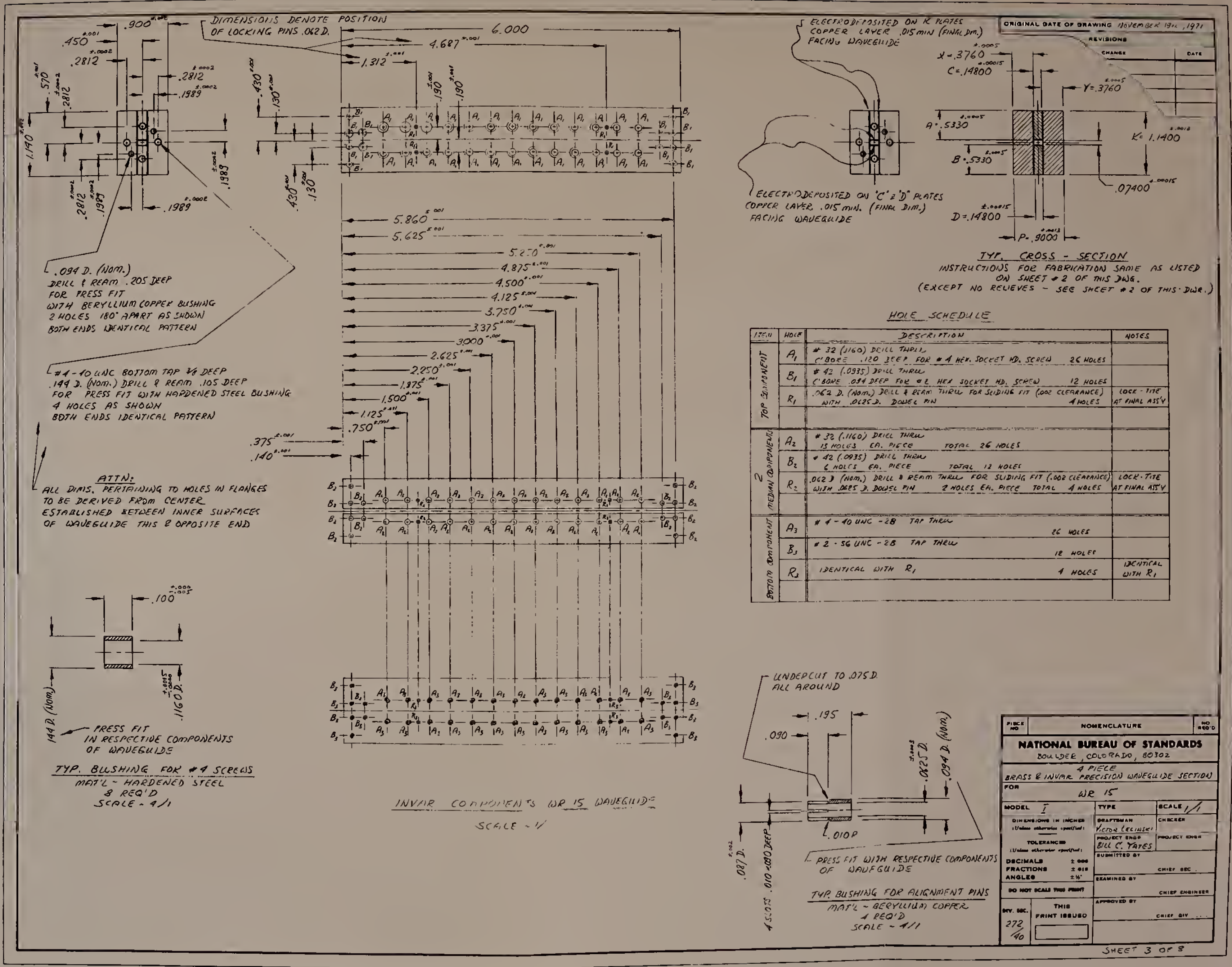

ORIGINAL DATE OF DRAWING NOVEMBER 19th, 1971
REVISIONS
CHANGE
DATE
D ON K PLATES
.015 MIN (FINAL DIM.)
DE
.90
±.001 .450
±.0002 .2812
±.001 .570
±.0002 .2812
±.002 1.140
±.0002 .2812
±.0002 .1989
2 "D" PLATES
AL DIM.)
±.0005 X=.3760
±.00015 C=.14800
±.0005 Y=.3760
±.0005 A=.5330
±.0005 B=.5330
±.0013 K=1.1400
.07400 ±.00015
±.00015 D=.14800
±.0013 P=.9000
TYP. CROSS - SECTION
INSTRUCTIONS FOR FABRICATION SAME AS LISTED ON SHEET #2 OF THIS DWG.
(EXCEPT NO RELIEVES - SEE SHEET #2 OF THIS DWG.)
.094 D. (NOM.)
DRILL & REAM .20
FOR PRESS FIT
WITH BERYLLIUM
2 HOLES 180° APA
BOTH ENDS IDENTIC
#4-40 UNC BOT
.144 D. (NOM.) DRIL
FOR PRESS FIT
4 HOLES AS SH
BOTH ENDS IDEN
ATTN:
ALL DIMS. PERTAI
TO BE DERIVED FR
ESTABLISHED BET
OF WAVEGUIDE
HOLE SCHEDULE
DESCRIPTION
NOTES
L THRU
EEP FOR #4 HEX. SOCKET HD. SCREW 26 HOLES
L THRU
FOR #2 HEX. SOCKET HD. SCREW 12 HOLES
LL & REAM THRU FOR SLIDING FIT (.002 CLEARANCE)
DOWEL PIN 4 HOLES
LOCK-TITE AT FINAL ASS'Y
L THRU
PIECE TOTAL 26 HOLES
LL THRU
PIECE TOTAL 12 HOLES
L & REAM THRU FOR SLIDING FIT (.002 CLEARANCE)
EL PIN 2 HOLES EA. PIECE TOTAL 4 HOLES
LOCK-TITE AT FINAL ASS'Y
B TAP THRU
26 HOLES
B TAP THRU
12 HOLES
H R1
4 HOLES
IDENTICAL WITH R1
.144 D. (NOM.)
PRESS FI
IN RESPEC
OF WAVE
TYP. BUSHIN
MAT'L ~ HA
8 REQ
SCALE
±.0003 .0625 D.
.094 D. (NOM.)
RESPECTIVE COMPONENTS
UIDE
FOR ALIGNMENT PINS
RYLLIUM COPPER
Q'D
~ 4/1
PIECE NO
NOMENCLATURE
NO REQ'D
NATIONAL BUREAU OF STANDARDS
BOULDER, COLORADO, 80302
4 PIECE
BRASS & INVAR PRECISION WAVEGUIDE SECTION
FOR
WR 15
MODEL I
TYPE
SCALE 1/1
DIMENSIONS IN INCHES (Unless otherwise specified)
TOLERANCES (Unless otherwise specified)
DECIMALS ±.000
FRACTIONS ±.01E
ANGLES ±½°
DO NOT SCALE THIS PRINT
DRAFTSMAN
VICTOR LECINSKI
CHECKER
PROJECT ENGR
BILL C. YATES
PROJECT ENGR
SUBMITTED BY
CHIEF, SEC.
EXAMINED BY
CHIEF ENGINEER
APPROVED BY
CHIEF, DIV
DIV. SEC.
272/40
THIS PRINT ISSUED
SHEET 3 OF 3

Figure 25



DIMENSIONS DENOTE POSITION
OF LOCKING PINS .062 D.

.094 D. (NOM.)
DRILL & REAM .205 DEEP
FOR PRESS FIT
WITH BERYLLIUM COPPER BUSHING
2 HOLES 180° APART AS SHOWN
BOTH ENDS IDENTICAL PATTERN

#4-40 UNC BOTTOM TAP 3/8 DEEP
.144 D. (NOM.) DRILL & REAM .105 DEEP
FOR PRESS FIT WITH HARDENED STEEL BUSHING
4 HOLES AS SHOWN
BOTH ENDS IDENTICAL PATTERN

ATTN:
ALL DIMS. PERTAINING TO HOLES IN FLANGES
TO BE DERIVED FROM CENTER
ESTABLISHED BETWEEN INNER SURFACES
OF WAVEGUIDE THIS & OPPOSITE END

ELECTRODEPOSITED ON K PLATES
COPPER LAYER .015 MIN (FINAL DIM.)
FACING WAVEGUIDE

ELECTRODEPOSITED ON "C" & "D" PLATES
COPPER LAYER .015 MIN. (FINAL DIM.)
FACING WAVEGUIDE

TYP. CROSS - SECTION
INSTRUCTIONS FOR FABRICATION SAME AS LISTED
ON SHEET #2 OF THIS DWG.
(EXCEPT NO RELIEVES - SEE SHEET #2 OF THIS DWG.)

ORIGINAL DATE OF DRAWING NOVEMBER 19th, 1971

REVISIONS	
CHANGE	DATE

HOLE SCHEDULE

ITEM	HOLE	DESCRIPTION	NOTES
TOP COMPONENT	A_1	# 32 (.1160) DRILL THRU C'BORE .120 DEEP FOR #4 HEX. SOCKET HD. SCREW 26 HOLES	
	B_1	# 42 (.0935) DRILL THRU C'BORE .094 DEEP FOR #2 HEX SOCKET HD. SCREW 12 HOLES	
	R_1	.062 D. (NOM.) DRILL & REAM THRU FOR SLIDING FIT (.002 CLEARANCE) WITH .0625 D. DOWEL PIN 4 HOLES	LOCK-TITE AT FINAL ASS'Y
2 MEDIAN COMPONENTS	A_2	# 32 (.1160) DRILL THRU 13 HOLES EA. PIECE TOTAL 26 HOLES	
	B_2	# 42 (.0935) DRILL THRU 6 HOLES EA. PIECE TOTAL 12 HOLES	
	R_2	.062 D (NOM.) DRILL & REAM THRU FOR SLIDING FIT (.002 CLEARANCE) WITH .0625 D. DOWEL PIN 2 HOLES EA. PIECE TOTAL 4 HOLES	LOCK-TITE AT FINAL ASS'Y
BOTTOM COMPONENT	A_3	# 4 - 40 UNC - 2B TAP THRU 26 HOLES	
	B_3	# 2 - 56 UNC - 2B TAP THRU 12 HOLES	
	R_3	IDENTICAL WITH R_1 4 HOLES	IDENTICAL WITH R_1

TYP. BUSHING FOR #4 SCREWS
MAT'L - HARDENED STEEL
8 REQ'D
SCALE - 4/1

PRESS FIT
IN RESPECTIVE COMPONENTS
OF WAVEGUIDE

INVAR COMPONENTS WR 15 WAVEGUIDE
SCALE - 1/1

UNDERCUT TO .075 D.
ALL AROUND

PRESS FIT WITH RESPECTIVE COMPONENTS
OF WAVEGUIDE

TYP. BUSHING FOR ALIGNMENT PINS
MAT'L - BERYLLIUM COPPER
4 REQ'D
SCALE - 4/1

PIECE NO | NOMENCLATURE | NO REQ'D

NATIONAL BUREAU OF STANDARDS
BOULDER, COLORADO, 80302

4 PIECE
BRASS & INVAR PRECISION WAVEGUIDE SECTION
FOR WR 15

MODEL I
TYPE
SCALE 1/1
DIMENSIONS IN INCHES (Unless otherwise specified)
TOLERANCES (Unless otherwise specified)
DECIMALS ± .005
FRACTIONS ± .015
ANGLES ± ½°
DO NOT SCALE THIS PRINT
DRAFTSMAN Victor Lecinski
CHECKER
PROJECT ENGR Bill C. Yates
PROJECT ENGR
SUBMITTED BY
CHIEF SEC.
EXAMINED BY
CHIEF ENGINEER
APPROVED BY
CHIEF DIV.
DIV. SEC. 272/40
THIS PRINT ISSUED

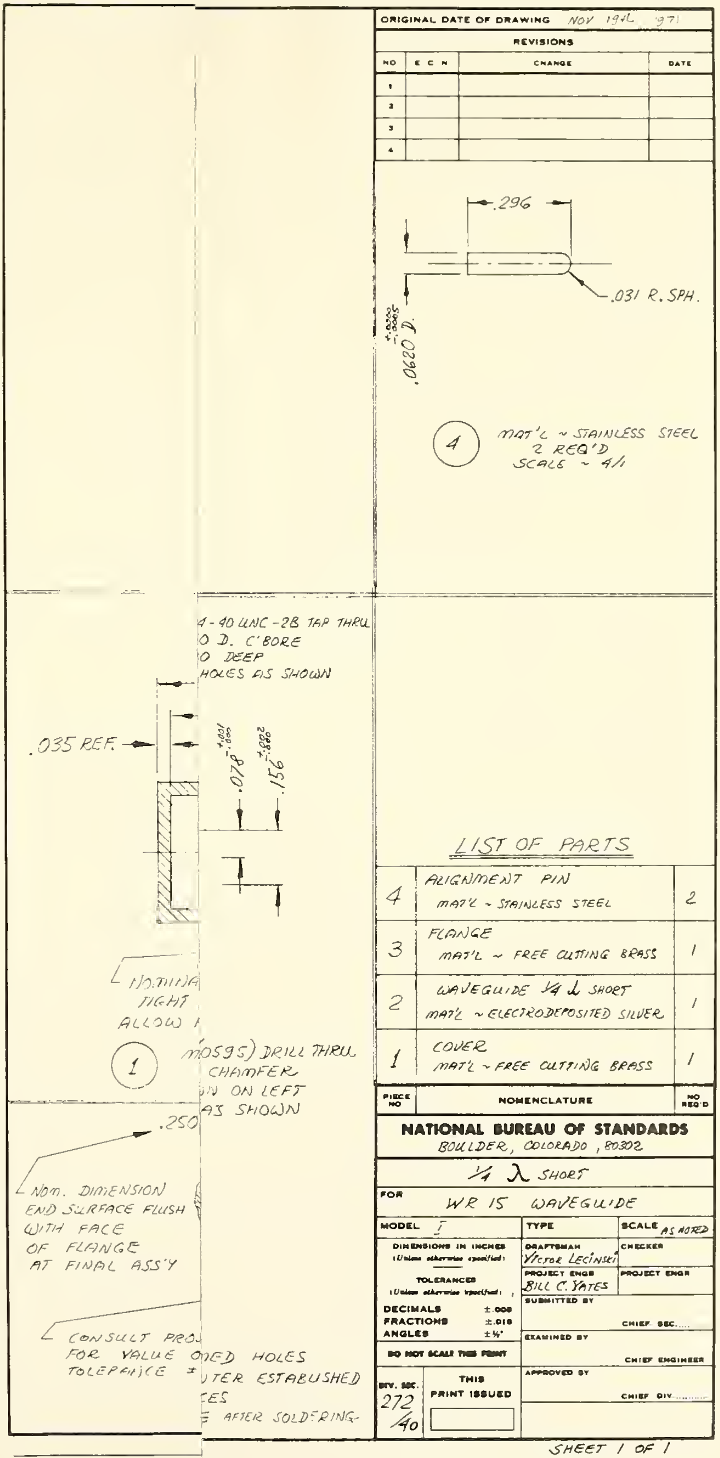
SHEET 3 OF 3

Figure 25(c).

APPENDIX H

Machine drawing for quarter-wave short circuit for WR15 waveguide.

Figure 26



LIST OF PARTS

PIECE NO	NOMENCLATURE	NO REQ'D
4	ALIGNMENT PIN MAT'L ~ STAINLESS STEEL	2
3	FLANGE MAT'L ~ FREE CUTTING BRASS	1
2	WAVEGUIDE 1/4 λ SHORT MAT'L ~ ELECTRODEPOSITED SILVER	1
1	COVER MAT'L ~ FREE CUTTING BRASS	1

NATIONAL BUREAU OF STANDARDS
BOULDER, COLORADO, 80302

1/4 λ SHORT

FOR WR 15 WAVEGUIDE

MODEL I
TYPE
SCALE AS NOTED

DIMENSIONS IN INCHES (Unless otherwise specified)
TOLERANCES (Unless otherwise specified)
DECIMALS ±.005
FRACTIONS ±.015
ANGLES ±½°
DO NOT SCALE THIS PRINT

DRAFTSMAN Victor Lecinski
CHECKER
PROJECT ENGR Bill C. Yates
PROJECT ENGR
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APPROVED BY
CHIEF DIV.

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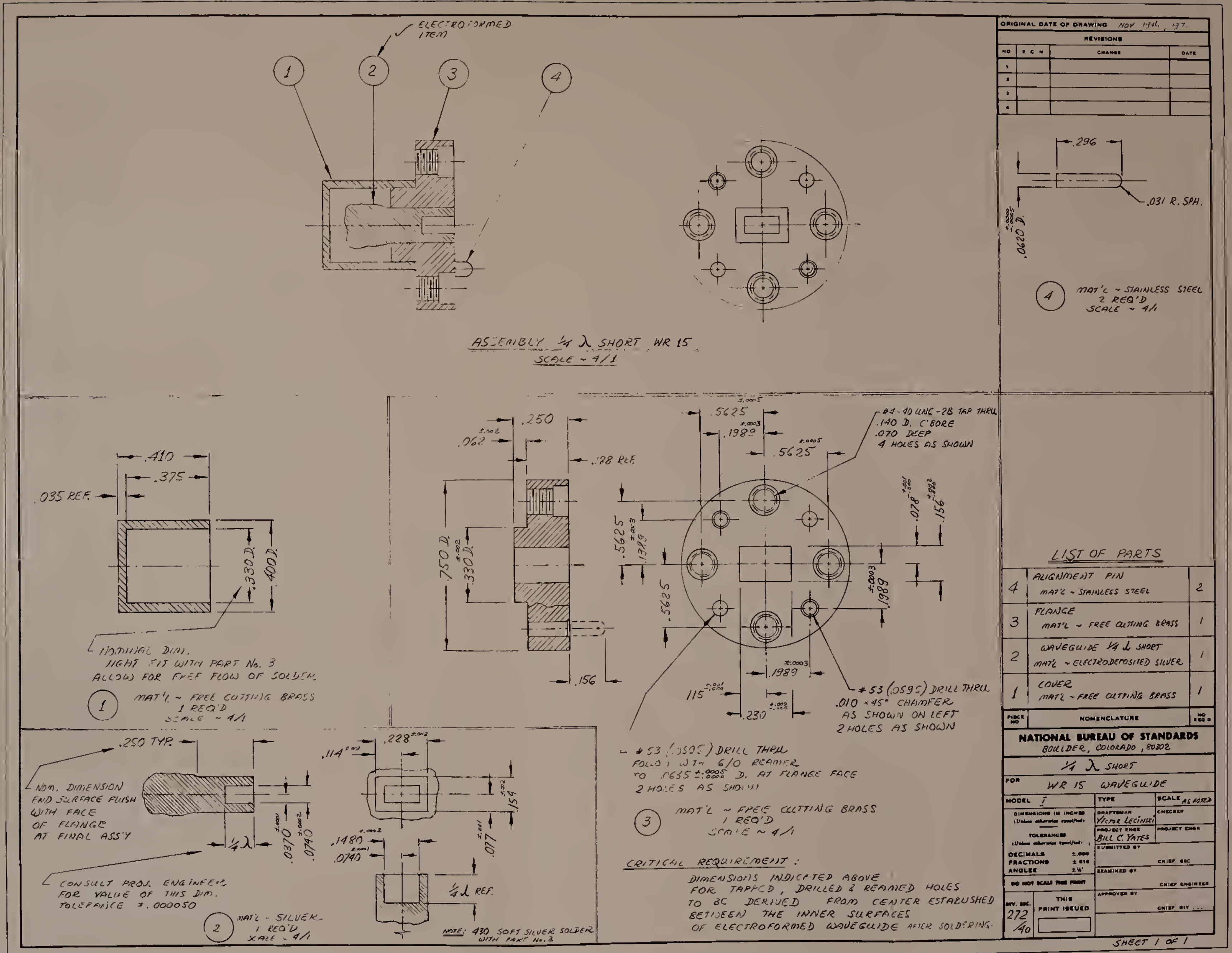
SHEET 1 OF 1

Figure 26.


ELECTROFORMED ITEM
1
2
3
4
ASSEMBLY 1/4 λ SHORT WR 15
SCALE ~ 4/1
ORIGINAL DATE OF DRAWING NOV 19th, 197
REVISIONS
NO
E C N
CHANGE
DATE
1
2
3
4
.296
.031 R. SPH.
.0620 D. +.0000 −.0005
4 MAT'L ~ STAINLESS STEEL
2 REQ'D
SCALE ~ 4/1
.410
.375
.035 REF.
.330 D.
.400 D.
NOMINAL DIM.
TIGHT FIT WITH PART No. 3
ALLOW FOR FREE FLOW OF SOLDER
1 MAT'L ~ FREE CUTTING BRASS
1 REQ'D
SCALE ~ 4/1
.250
.062 ±.002
.188 REF.
.750 D.
.330 D. ±.002
.156
.5625 ±.0005
.1989 ±.0003
.5625 ±.0005
#4-40 UNC-2B TAP THRU
.140 D. C'BORE
.070 DEEP
4 HOLES AS SHOWN
.5625
.1989 ±.0003
.5625
.078 +.001 −.000
.156 +.002
.1989 ±.0003
.1989 ±.0003
.115 +.001 −.000
.230 ±.002
#53 (.0595) DRILL THRU
.010 × 45° CHAMFER
AS SHOWN ON LEFT
2 HOLES AS SHOWN
#53 (.0595) DRILL THRU
FOLLOW WITH 6/0 REAMER
TO .0635 +.0005 −.0000 D. AT FLANGE FACE
2 HOLES AS SHOWN
3 MAT'L ~ FREE CUTTING BRASS
1 REQ'D
SCALE ~ 4/1
CRITICAL REQUIREMENT :
DIMENSIONS INDICATED ABOVE
FOR TAPPED, DRILLED & REAMED HOLES
TO BE DERIVED FROM CENTER ESTABLISHED
BETWEEN THE INNER SURFACES
OF ELECTROFORMED WAVEGUIDE AFTER SOLDERING.
.250 TYP.
NOM. DIMENSION
END SURFACE FLUSH
WITH FACE
OF FLANGE
AT FINAL ASS'Y
1/4 λ
.0370 ±.001
.0740 ±.0002
CONSULT PROJ. ENGINEER
FOR VALUE OF THIS DIM.
TOLERANCE ±.000050
2 MAT'L ~ SILVER
1 REQ'D
SCALE ~ 4/1
.228 ±.002
.114 ±.001
.154 ±.002
.077 ±.001
.1480 ±.0002
.0740 ±.0001
1/4 λ REF.
NOTE: 430 SOFT SILVER SOLDER WITH PART No. 3
LIST OF PARTS
4 ALIGNMENT PIN MAT'L ~ STAINLESS STEEL 2
3 FLANGE MAT'L ~ FREE CUTTING BRASS 1
2 WAVEGUIDE 1/4 λ SHORT MAT'L ~ ELECTRODEPOSITED SILVER 1
1 COVER MAT'L ~ FREE CUTTING BRASS 1
PIECE NO
NOMENCLATURE
NO REQ'D
NATIONAL BUREAU OF STANDARDS
BOULDER, COLORADO, 80302
1/4 λ SHORT
FOR WR 15 WAVEGUIDE
MODEL I
TYPE
SCALE AS NOTED
DIMENSIONS IN INCHES (Unless otherwise specified)
TOLERANCES (Unless otherwise specified)
DECIMALS ±.005
FRACTIONS ±.010
ANGLES ±1/2°
DRAFTSMAN Victor Lecinski
CHECKER
PROJECT ENGR Bill C. Yates
PROJECT ENGR
SUBMITTED BY
CHIEF SEC
EXAMINED BY
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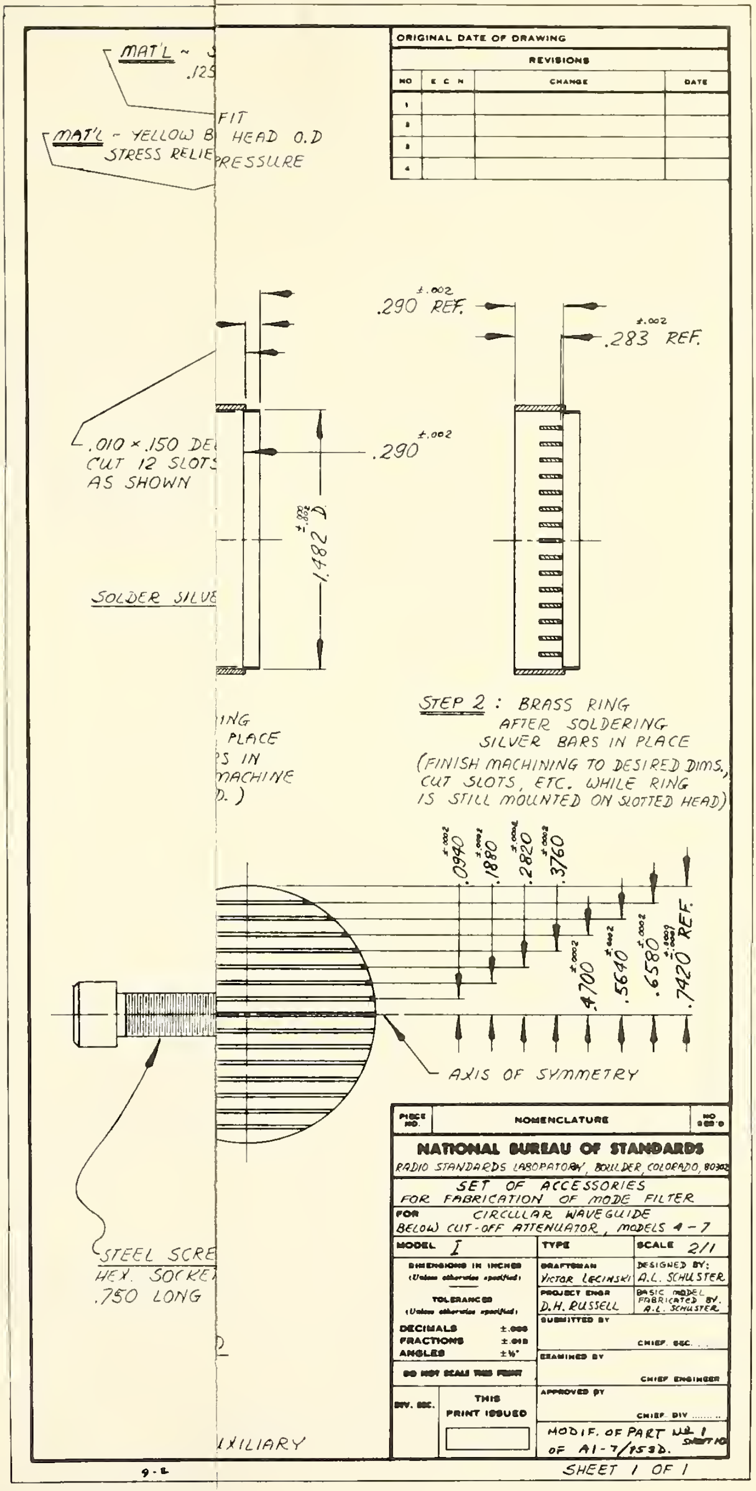
SHEET 1 OF 1

Figure 26.

APPENDIX I

Machine drawing for circular waveguide below-cutoff attenuator for nominal 30 MHz operation.

Figures 27(a) thru 27(n)



ORIGINAL DATE OF DRAWING

REVISIONS

NO	E C N	CHANGE	DATE
1			
2			
3			
4			

PIECE NO. | NOMENCLATURE | NO. REQ'D

NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER, COLORADO, 80302
SET OF ACCESSORIES
FOR FABRICATION OF MODE FILTER
FOR CIRCULAR WAVEGUIDE
BELOW CUT-OFF ATTENUATOR, MODELS 4 - 7
MODEL I
TYPE
SCALE 2/1
DIMENSIONS IN INCHES (Unless otherwise specified)
DRAFTSMAN Victor Lecinski
DESIGNED BY: A.L. SCHUSTER
TOLERANCES (Unless otherwise specified)
PROJECT ENGR D.H. RUSSELL
BASIC MODEL FABRICATED BY. A.L. SCHUSTER
DECIMALS ±.000
FRACTIONS ±.010
ANGLES ±½°
SUBMITTED BY
CHIEF. SEC.
EXAMINED BY
DO NOT SCALE THIS PRINT
CHIEF ENGINEER
APPROVED BY
DIV. SEC.
THIS PRINT ISSUED
CHIEF. DIV
MODIF. OF PART No. 1 SHEET 10
OF A1-7/953D.
SHEET 1 OF 1

Figure 27

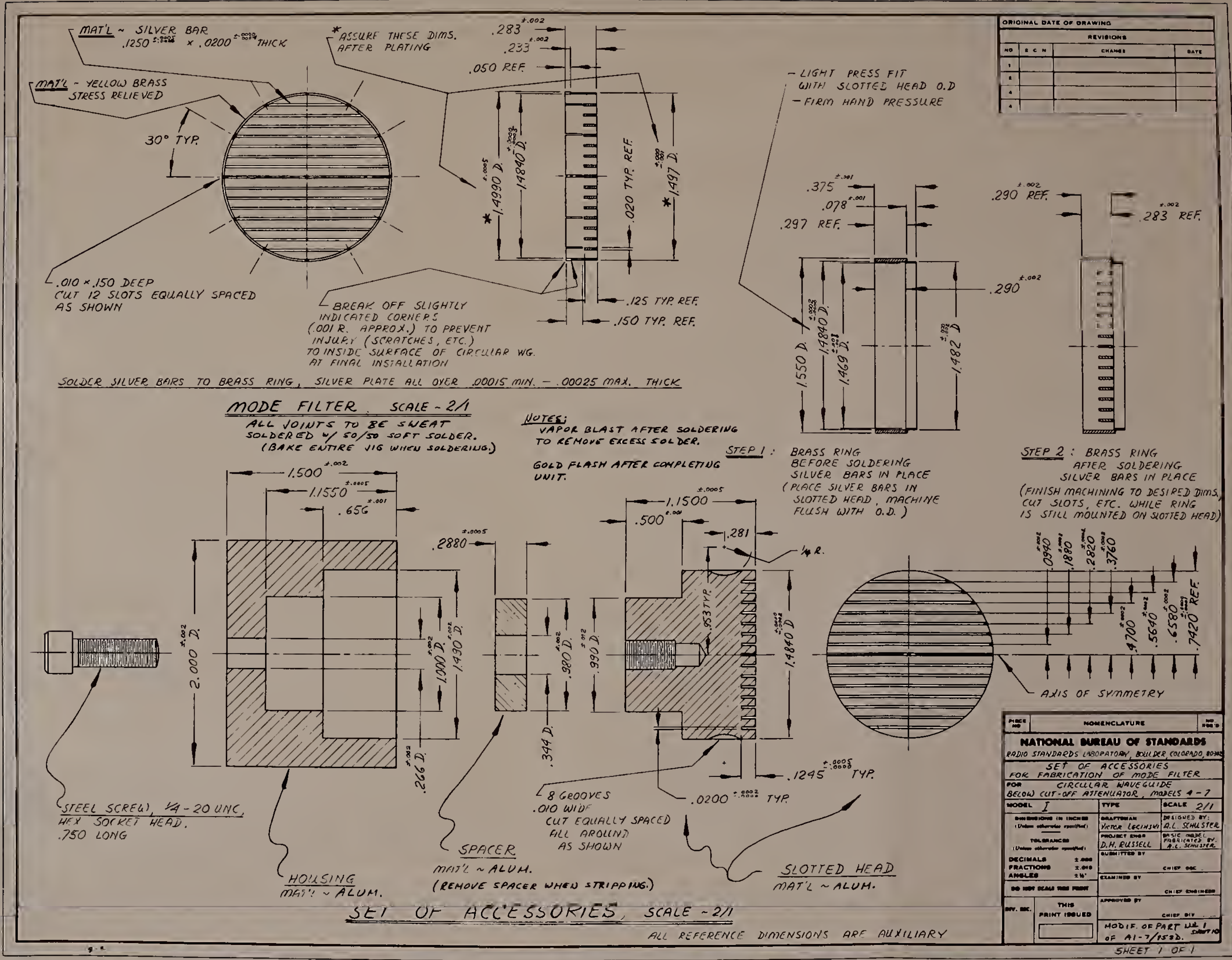
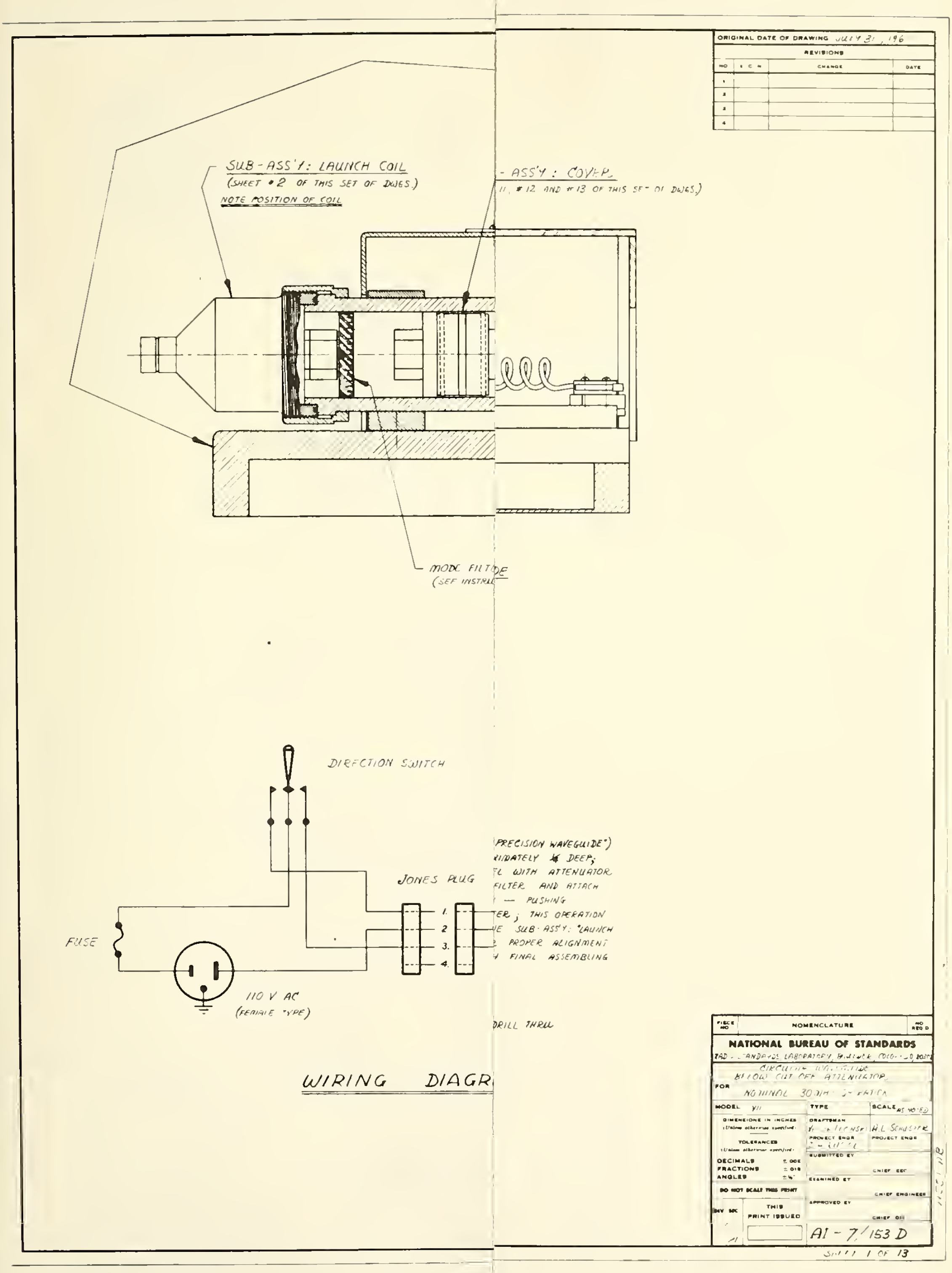

MAT'L ~ SILVER BAR .1250 × .0200 THICK
MAT'L ~ YELLOW BRASS STRESS RELIEVED
30° TYP.
.010 × .150 DEEP CUT 12 SLOTS EQUALLY SPACED AS SHOWN
*ASSURE THESE DIMS. AFTER PLATING
.283 ±.002
.233 ±.002
.050 REF.
*1.4990 D.
1.4840 D.
.020 TYP. REF.
*1.497 D.
.125 TYP. REF.
.150 TYP. REF.
BREAK OFF SLIGHTLY INDICATED CORNERS (.001 R. APPROX.) TO PREVENT INJURY (SCRATCHES, ETC.) TO INSIDE SURFACE OF CIRCULAR WG. AT FINAL INSTALLATION
SOLDER SILVER BARS TO BRASS RING, SILVER PLATE ALL OVER .00015 MIN. – .00025 MAX. THICK
MODE FILTER, SCALE ~ 2/1
– LIGHT PRESS FIT WITH SLOTTED HEAD O.D
– FIRM HAND PRESSURE
.375
.078 ±.001
.297 REF.
1.550 D.
1.4840 D.
1.469 D.
1.482 D
.290 ±.002
STEP 1 : BRASS RING BEFORE SOLDERING SILVER BARS IN PLACE (PLACE SILVER BARS IN SLOTTED HEAD, MACHINE FLUSH WITH O.D.)
.290 REF.
.283 REF.
STEP 2 : BRASS RING AFTER SOLDERING SILVER BARS IN PLACE (FINISH MACHINING TO DESIRED DIMS, CUT SLOTS, ETC. WHILE RING IS STILL MOUNTED ON SLOTTED HEAD)
ALL JOINTS TO BE SWEAT SOLDERED W/ 50/50 SOFT SOLDER. (BAKE ENTIRE JIG WHEN SOLDERING.)
NOTES: VAPOR BLAST AFTER SOLDERING TO REMOVE EXCESS SOLDER.
GOLD FLASH AFTER COMPLETING UNIT.
1.500 ±.002
1.1550 ±.0005
.656 ±.001
2.000 D.
1.000 D.
1.430 D.
.266 D.
.2880 ±.0005
.980 D.
.990 D.
.344 D.
1.1500 ±.0005
.500 ±.001
.281
1/4 R.
.953 TYP.
1.4840 D
.1245 ±.0005 TYP.
.0200 TYP.
.0940
.1880
.2820
.3760
.4700
.5640
.6580
.7420 REF.
AXIS OF SYMMETRY
STEEL SCREW, 1/4-20 UNC, HEX SOCKET HEAD, .750 LONG
HOUSING MAT'L ~ ALUM.
SPACER MAT'L ~ ALUM. (REMOVE SPACER WHEN STRIPPING.)
8 GROOVES .010 WIDE CUT EQUALLY SPACED ALL AROUND AS SHOWN
SLOTTED HEAD MAT'L ~ ALUM.
SET OF ACCESSORIES, SCALE ~ 2/1
ALL REFERENCE DIMENSIONS ARE AUXILIARY
ORIGINAL DATE OF DRAWING
REVISIONS
NO
E C N
CHANGE
DATE
PIECE NO
NOMENCLATURE
NO. REQ'D
NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER, COLORADO, 80302
SET OF ACCESSORIES FOR FABRICATION OF MODE FILTER
FOR CIRCULAR WAVEGUIDE BELOW CUT-OFF ATTENUATOR, MODELS 4 – 7
MODEL I
TYPE
SCALE 2/1
DIMENSIONS IN INCHES (Unless otherwise specified)
TOLERANCES (Unless otherwise specified)
DECIMALS ±.000
FRACTIONS ±.010
ANGLES ±½°
DO NOT SCALE THIS PRINT
DRAFTSMAN VICTOR LECINSKI
DESIGNED BY: A.L. SCHUSTER
PROJECT ENGR D.H. RUSSELL
BASIC MODEL FABRICATED BY: A.L. SCHUSTER
SUBMITTED BY
CHIEF SEC.
EXAMINED BY
CHIEF ENGINEER
APPROVED BY
CHIEF DIV.
DIV. SEC.
THIS PRINT ISSUED
MODIF. OF PART NO. 1 SHEET 10 OF A1-7/153D.
SHEET 1 OF 1

Figure 27(a).


ORIGINAL DATE OF DRAWING JULY 31, 196
REVISIONS
NO
I C N
CHANGE
DATE
1
2
3
4
SUB-ASS'Y: LAUNCH COIL
(SHEET #2 OF THIS SET OF DWGS.)
NOTE POSITION OF COIL
- ASS'Y : COVER
11, # 12 AND # 13 OF THIS SET OF DWGS.)
MODE FILTER
(SEE INSTRU
DIRECTION SWITCH
PRECISION WAVEGUIDE")
XIMATELY DEEP;
EL WITH ATTENUATOR
FILTER AND ATTACH
— PUSHING
TER ; THIS OPERATION
HE SUB-ASS'Y: "LAUNCH
PROPER ALIGNMENT
FINAL ASSEMBLING
JONES PLUG
1.
2
3.
4.
FUSE
110 V AC
(FEMALE TYPE)
DRILL THRU
WIRING DIAGR
PIECE NO
NOMENCLATURE
NO REQ D
NATIONAL BUREAU OF STANDARDS
RAD - STANDARDS LABORATORY, BOULDER, COLORADO, 80302
CIRCULAR WAVEGUIDE
BELOW CUT OFF ATTENUATOR
FOR
NOMINAL 30 MHz OPERATION
MODEL VII
TYPE
SCALE AS NOTED
DIMENSIONS IN INCHES
(Unless otherwise specified)
TOLERANCES
(Unless otherwise specified)
DECIMALS ± .005
FRACTIONS ± .015
ANGLES ± ½°
DO NOT SCALE THIS PRINT
DRAFTSMAN
H.L. SCHUSTER
PROJECT ENGR
PROJECT ENGR
SUBMITTED BY
CHIEF SEC
EXAMINED BY
CHIEF ENGINEER
APPROVED BY
CHIEF DIV
INV SEC
THIS PRINT ISSUED
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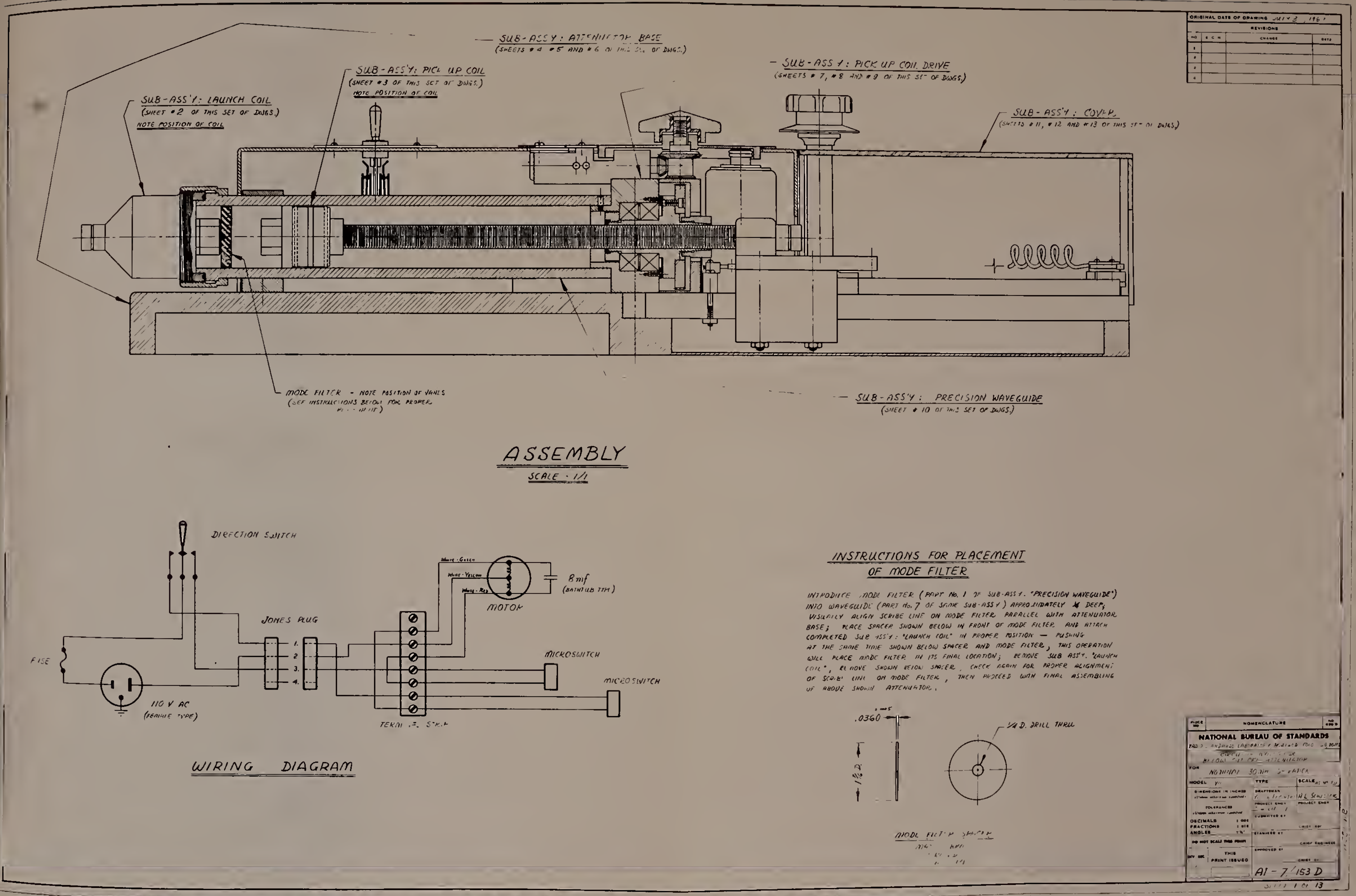
SHEET 1 OF 13

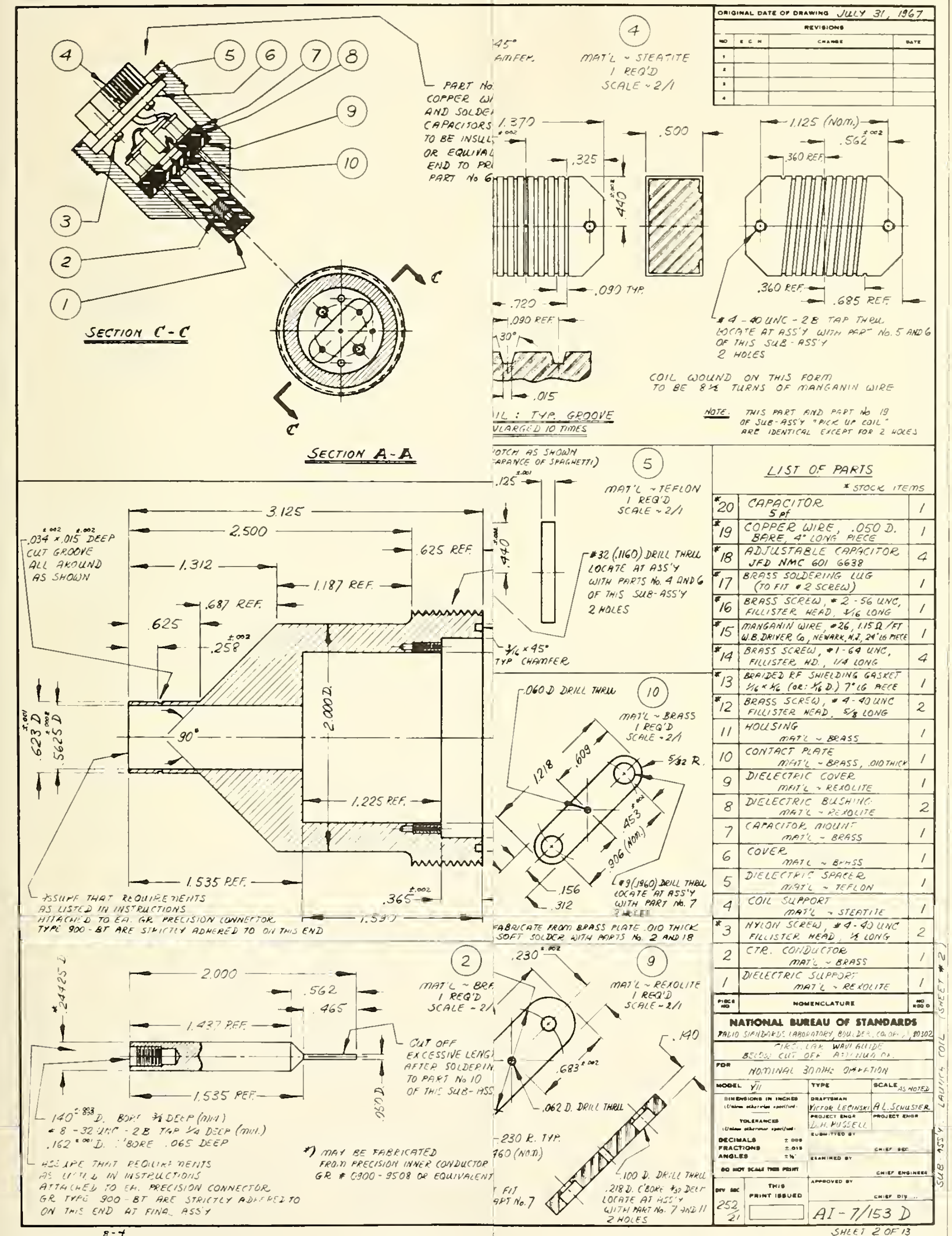
Figure 27(b).



INSTRUCTIONS FOR PLACEMENT OF MODE FILTER

INTRODUCE MODE FILTER (PART No. 1 OF SUB-ASSY. "PRECISION WAVEGUIDE") INTO WAVEGUIDE (PART No. 7 OF SAME SUB-ASSY) APPROXIMATELY 1/4 DEEP; VISUALLY ALIGN SCRIBE LINE ON MODE FILTER PARALLEL WITH ATTENUATOR BASE; PLACE SPACER SHOWN BELOW IN FRONT OF MODE FILTER AND ATTACH COMPLETED SUB ASS'Y: "LAUNCH COIL" IN PROPER POSITION — PUSHING AT THE SAME TIME SHOWN BELOW SPACER AND MODE FILTER, THIS OPERATION WILL PLACE MODE FILTER IN ITS FINAL LOCATION; REMOVE SUB ASS'Y. "LAUNCH COIL", REMOVE SHOWN BELOW SPACER, CHECK AGAIN FOR PROPER ALIGNMENT OF SCRIBE LINE ON MODE FILTER, THEN PROCEED WITH FINAL ASSEMBLING OF ABOVE SHOWN ATTENUATOR.

Figure 27(b).



LIST OF PARTS

* STOCK ITEMS

PIECE NO	NOMENCLATURE	NO REQ'D
*20	CAPACITOR 5 pf	1
*19	COPPER WIRE, .050 D. BARE, 4" LONG PIECE	1
*18	ADJUSTABLE CAPACITOR JFD NMC 601 6638	4
*17	BRASS SOLDERING LUG (TO FIT #2 SCREW)	1
*16	BRASS SCREW, #2-56 UNC, FILLISTER HEAD, 3/16 LONG	1
*15	MANGANIN WIRE, #26, 1.15 Ω/FT W.B. DRIVER Co, NEWARK, N.J., 24" LG PIECE	1
*14	BRASS SCREW, #1-64 UNC, FILLISTER HD., 1/4 LONG	4
*13	BRAIDED RF SHIELDING GASKET 1/16 × 1/16 (OR: 1/16 D.) 7" LG PIECE	1
*12	BRASS SCREW, #4-40 UNC FILLISTER HEAD, 5/8 LONG	2
11	HOUSING MAT'L ~ BRASS	1
10	CONTACT PLATE MAT'L ~ BRASS, .010 THICK	1
9	DIELECTRIC COVER MAT'L ~ REXOLITE	1
8	DIELECTRIC BUSHING MAT'L ~ REXOLITE	2
7	CAPACITOR MOUNT MAT'L ~ BRASS	1
6	COVER MAT'L ~ BRASS	1
5	DIELECTRIC SPACER MAT'L ~ TEFLON	1
4	COIL SUPPORT MAT'L ~ STEATITE	1
*3	NYLON SCREW, #4-40 UNC FILLISTER HEAD, 1/2 LONG	2
2	CTR. CONDUCTOR MAT'L ~ BRASS	1
1	DIELECTRIC SUPPORT MAT'L ~ REXOLITE	1

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RADIO STANDARDS LABORATORY, BOULDER, COLORADO, 80302

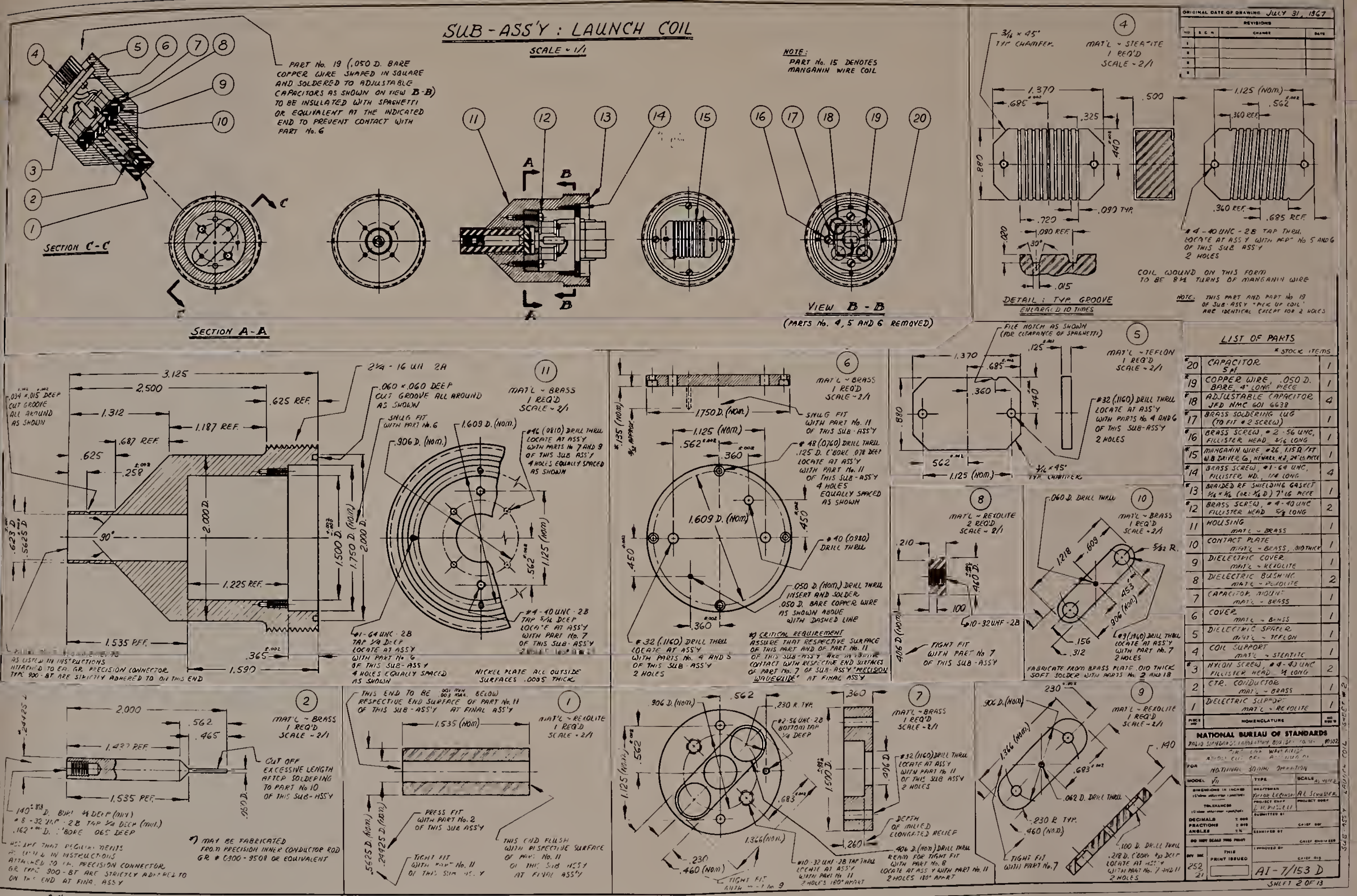
CIRCULAR WAVEGUIDE
BELOW CUT OFF ATTENUATOR

FOR NOMINAL 30 MHz OPERATION

MODEL VII	TYPE	SCALE AS NOTED
DIMENSIONS IN INCHES (Unless otherwise specified) TOLERANCES (Unless otherwise specified) DECIMALS ± .005 FRACTIONS ± .015 ANGLES ± ½° DO NOT SCALE THIS PRINT	DRAFTSMAN VICTOR LECINSKI PROJECT ENGR L.H. RUSSELL	A.L. SCHUSTER PROJECT ENGR
	SUBMITTED BY CHIEF SEC.	
	EXAMINED BY CHIEF ENGINEER	
DIV SEC 252/21	THIS PRINT ISSUED ☐	APPROVED BY CHIEF DIV.
		AI-7/153 D

SHEET 2 OF 13

Figure 27(c).



LIST OF PARTS

* STOCK ITEMS

PIECE NO.	NOMENCLATURE	NO. REQ'D
*20	CAPACITOR 5 pf	1
*19	COPPER WIRE, .050 D. BARE, 4" LONG PIECE	1
*18	ADJUSTABLE CAPACITOR JFD NMC 601 6638	4
*17	BRASS SOLDERING LUG (TO FIT #2 SCREW)	1
*16	BRASS SCREW, #2-56 UNC, FILLISTER HEAD 3/16 LONG	1
*15	MANGANIN WIRE, #26, 1.15 Ω /FT W.B DRIVER Co, NEWARK, N.J. 24" LG PIECE	1
*14	BRASS SCREW, #1-64 UNC, FILLISTER HD., 1/4 LONG	4
*13	BRAIDED RF SHIELDING GASKET 1/16 × 1/16 (OR: 1/16 D) 7" LG PIECE	1
*12	BRASS SCREW, #4-40 UNC FILLISTER HEAD 5/8 LONG	2
11	HOUSING MAT'L ~ BRASS	1
10	CONTACT PLATE MAT'L ~ BRASS, .010 THICK	1
9	DIELECTRIC COVER MAT'L ~ REXOLITE	1
8	DIELECTRIC BUSHING MAT'L ~ REXOLITE	2
7	CAPACITOR MOUNT MAT'L ~ BRASS	1
6	COVER MAT'L ~ BRASS	1
5	DIELECTRIC SPACER MAT'L ~ TEFLON	1
4	COIL SUPPORT MAT'L ~ STEATITE	1
*3	NYLON SCREW, #4-40 UNC FILLISTER HEAD 1/4 LONG	2
2	CTR. CONDUCTOR MAT'L ~ BRASS	1
1	DIELECTRIC SUPPORT MAT'L ~ REXOLITE	1

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RADIO STANDARDS LABORATORY, BOULDER, COLORADO, 80302

FOR NATIONAL [illegible]

MODEL VII

SCALE AS NOTED

DRAFTSMAN Victor Leginski

Al Schuster

DIMENSIONS IN INCHES (Unless otherwise specified)

TOLERANCES (Unless otherwise specified)
DECIMALS ± .002
FRACTIONS ± .010
ANGLES ± ½

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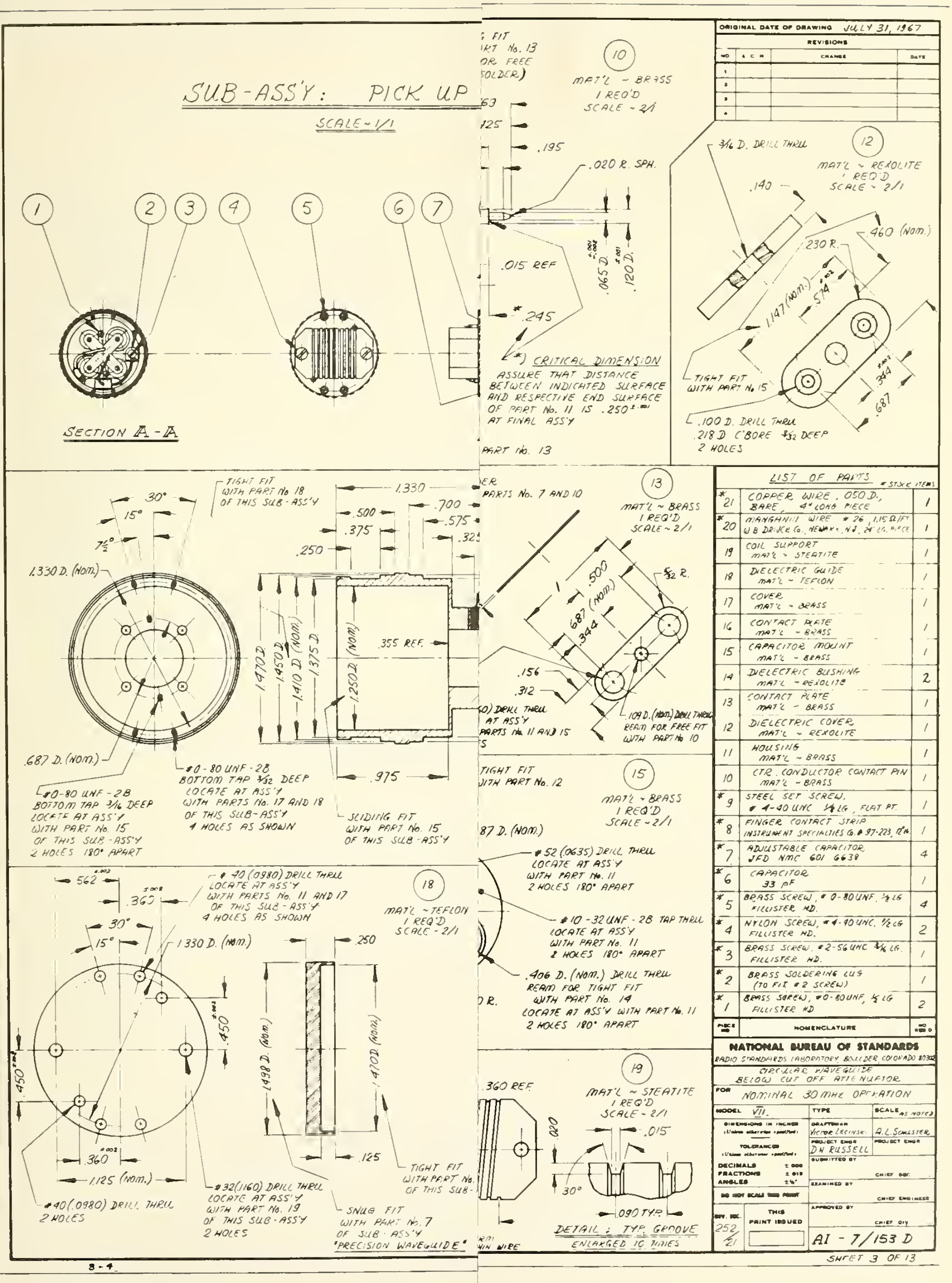
252/21

AI-7/153 D

Figure 27(c).



ORIGINAL DATE OF DRAWING JULY 31, 1967

REVISIONS			
NO	E C N	CHANGE	DATE
1			
2			
3			
4			

LIST OF PARTS

* STOCK ITEMS

PIECE NO	NOMENCLATURE	NO REQ'D
*21	COPPER WIRE, .050 D., BARE, 4" LONG PIECE	1
*20	MANGANIN WIRE #26, 1.15 Ω/FT W B DRIVER Co., NEWARK, N.J., 2" LG. PIECE	1
19	COIL SUPPORT MAT'L ~ STEATITE	1
18	DIELECTRIC GUIDE MAT'L ~ TEFLON	1
17	COVER MAT'L ~ BRASS	1
16	CONTACT PLATE MAT'L ~ BRASS	1
15	CAPACITOR MOUNT MAT'L ~ BRASS	1
14	DIELECTRIC BUSHING MAT'L ~ REXOLITE	2
13	CONTACT PLATE MAT'L ~ BRASS	1
12	DIELECTRIC COVER MAT'L ~ REXOLITE	1
11	HOUSING MAT'L ~ BRASS	1
10	CTR. CONDUCTOR CONTACT PIN MAT'L ~ BRASS	1
*9	STEEL SET SCREW, #4-40 UNC 1/8 LG, FLAT PT.	1
*8	FINGER CONTACT STRIP INSTRUMENT SPECIALTIES Co. #97-223, 12" LG.	1
*7	ADJUSTABLE CAPACITOR JFD NMC 601 6638	4
*6	CAPACITOR 33 pF	1
*5	BRASS SCREW, #0-80 UNF, 1/8 LG FILLISTER HD.	4
*4	NYLON SCREW, #4-40 UNC, 1/2 LG FILLISTER HD.	2
*3	BRASS SCREW, #2-56 UNC 3/16 LG. FILLISTER HD.	1
*2	BRASS SOLDERING LUG (TO FIT #2 SCREW)	1
*1	BRASS SCREW, #0-80 UNF, 1/8 LG FILLISTER HD	2

NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER, COLORADO 80302

CIRCULAR WAVEGUIDE
BELOW CUT OFF ATTENUATOR
FOR NOMINAL 30 MHz OPERATION

MODEL VII.	TYPE	SCALE AS NOTED
DIMENSIONS IN INCHES (Unless otherwise specified)	DRAFTSMAN Victor Lecinski	A.L. Schuster
TOLERANCES (Unless otherwise specified)	PROJECT ENGR D H RUSSELL	PROJECT ENGR
DECIMALS ±.000 FRACTIONS ±.010 ANGLES ±½°	SUBMITTED BY CHIEF SEC.	
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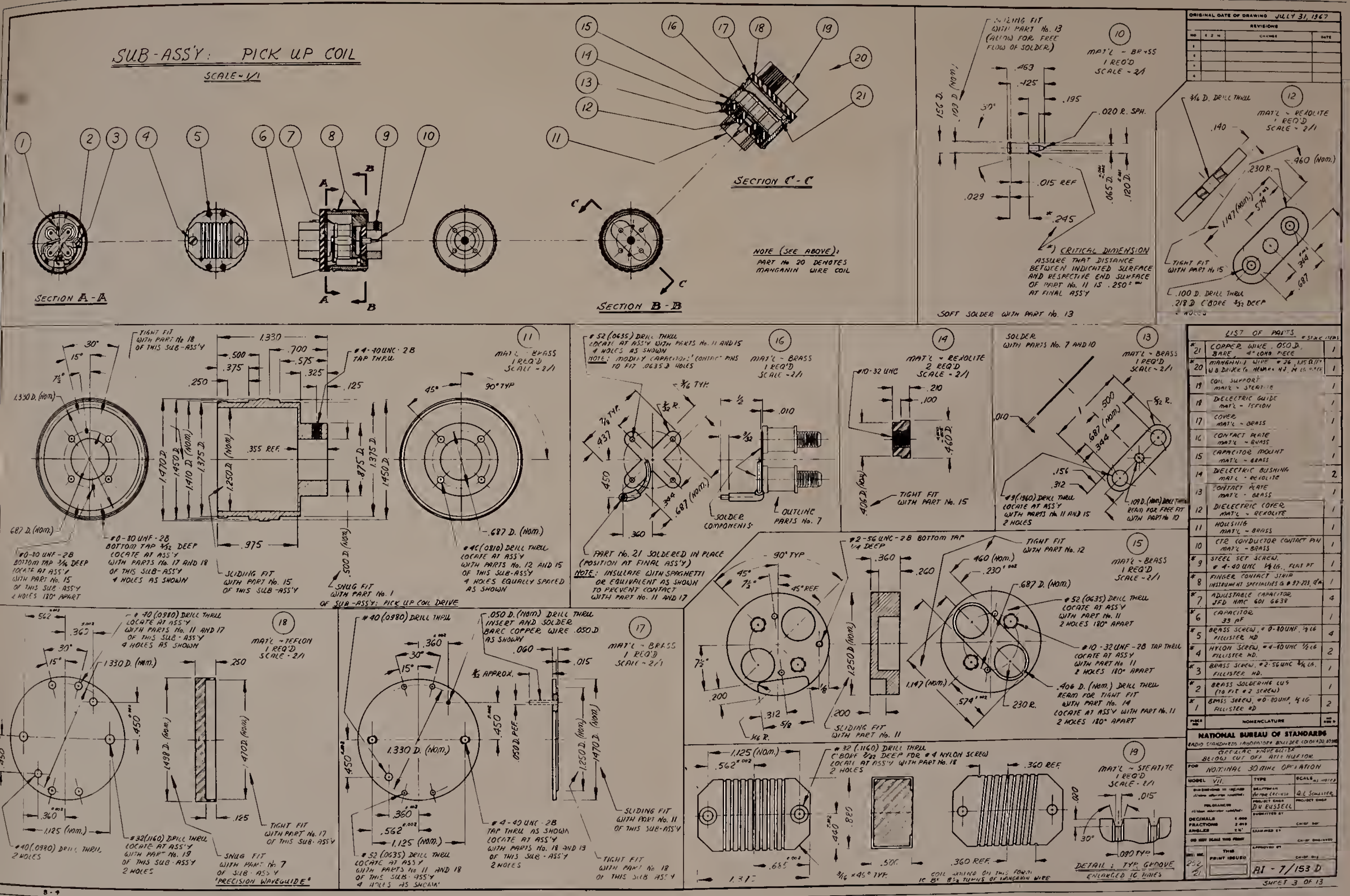
DIV. SEC. 252/21 — THIS PRINT ISSUED ☐	APPROVED BY CHIEF DIV	
	AI - 7/153 D	

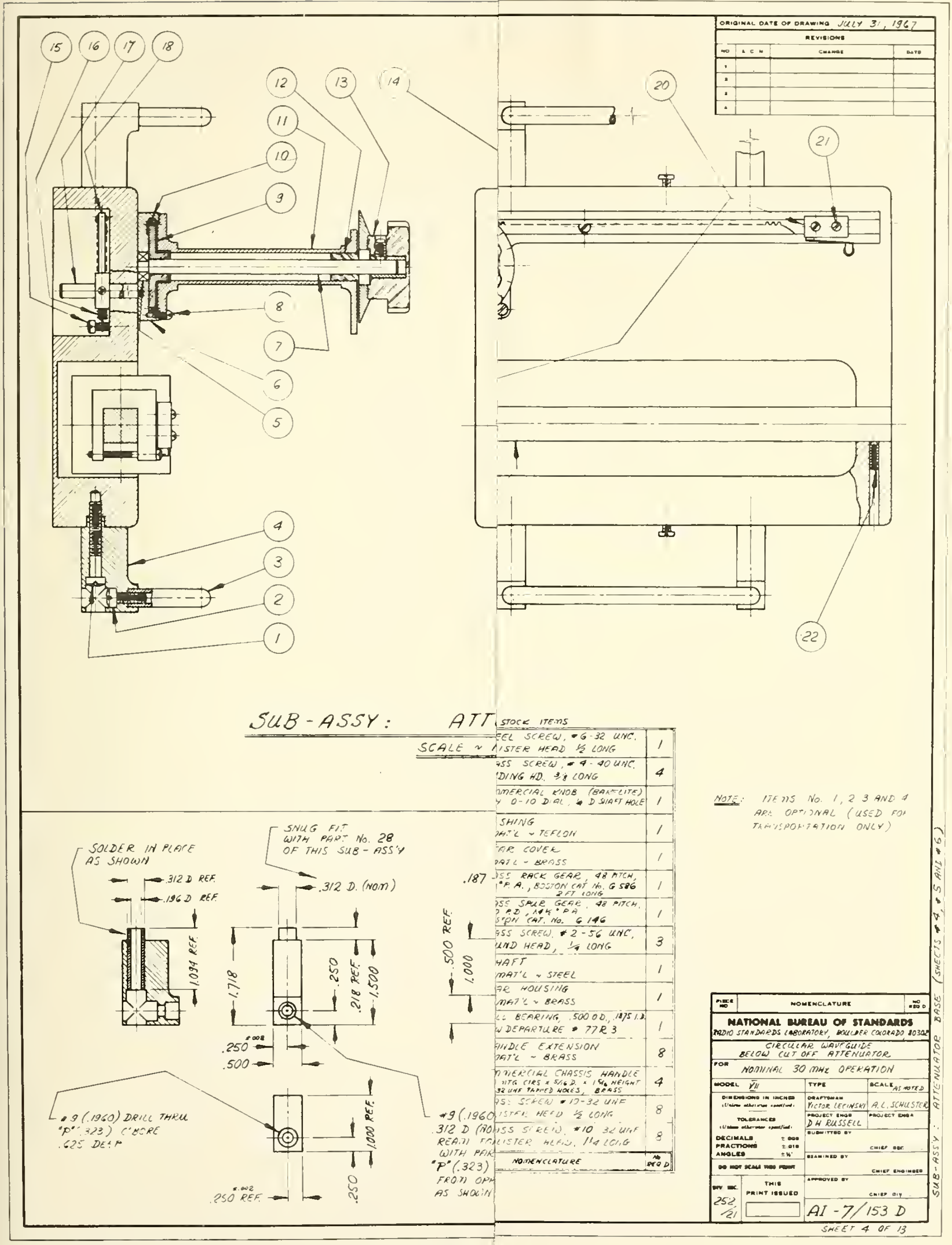
SHEET 3 OF 13

Figure 27(d).



	LIST OF PARTS	* STOCK ITEMS
*21	COPPER WIRE, .050 D. BARE, 4" LONG PIECE	1
*20	MANGANIN WIRE #26, 1.15 Ω/FT, U.B. DRIVER Co. NEWARK NJ	1
19	COIL SUPPORT MAT'L - STEATITE	1
18	DIELECTRIC GUIDE MAT'L - TEFLON	1
17	COVER MAT'L - BRASS	1
16	CONTACT PLATE MAT'L - BRASS	1
15	CAPACITOR MOUNT MAT'L - BRASS	1
14	DIELECTRIC BUSHING MAT'L - REXOLITE	2
13	CONTACT PLATE MAT'L - BRASS	1
12	DIELECTRIC COVER MAT'L - REXOLITE	1
11	HOUSING MAT'L - BRASS	1
10	CTR CONDUCTOR CONTACT PIN MAT'L - BRASS	1
*9	STEEL SET SCREW, #4-40 UNC ⅛ LG., FLAT PT	1
*8	FINGER CONTACT STRIP INSTRUMENT SPECIALTIES Co #97-223	1
*7	ADJUSTABLE CAPACITOR JFD NMC 601 6638	4
*6	CAPACITOR 33 pF	1
*5	BRASS SCREW, #0-80UNF, ⅛ LG FILLISTER HD	4
*4	NYLON SCREW, #4-40 UNC ½ LG FILLISTER HD.	2
*3	BRASS SCREW, #2-56 UNC ⅛ LG. FILLISTER HD.	1
*2	BRASS SOLDERING LUG (TO FIT #2 SCREW)	1
*1	BRASS SCREW, #0-80UNF, ⅛ LG FILLISTER HD	2
PIECE NO	NOMENCLATURE	REQ'D

Figure 27(d).



ORIGINAL DATE OF DRAWING	JULY 31, 1967		
REVISIONS			
NO	E C N	CHANGE	DATE
1			
2			
3			
4			

STOCK ITEMS

NOMENCLATURE	No REQ'D
EEL SCREW, # 6-32 UNC. ISTER HEAD ½ LONG	1
ASS SCREW, # 4-40 UNC. DING HD. 3/8 LONG	4
MERCIAL KNOB (BAKELITE) Y 0-10 DIAL, ¼ D SHAFT HOLE	1
SHING MAT'L ~ TEFLON	1
AR COVER MAT'L - BRASS	1
SS RACK GEAR, 48 PITCH, °P. A., BOSTON CAT. No. G 586 2 FT LONG	1
SS SPUR GEAR, 48 PITCH, P.D., 14½° P A STON CAT. No. G 146	1
ASS SCREW, # 2-56 UNC, UND HEAD, ¼ LONG	3
HAFT MAT'L ~ STEEL	1
AR HOUSING MAT'L ~ BRASS	1
L BEARING, .500 O.D., .1875 I.D. W DEPARTURE # 77R 3	1
ANDLE EXTENSION MAT'L ~ BRASS	8
MERCIAL CHASSIS HANDLE MTG CTRS × 5/16 D. × 1 9/16 HEIGHT 32 UNF TAPPED HOLES, BRASS	4
ASS SCREW # 10-32 UNF ISTER HEAD ½ LONG	8
ASS SCREW, # 10 32 UNF FILLISTER HEAD, 1¼ LONG	8

PIECE NO	NOMENCLATURE	NO REQ'D

NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER COLORADO 80302

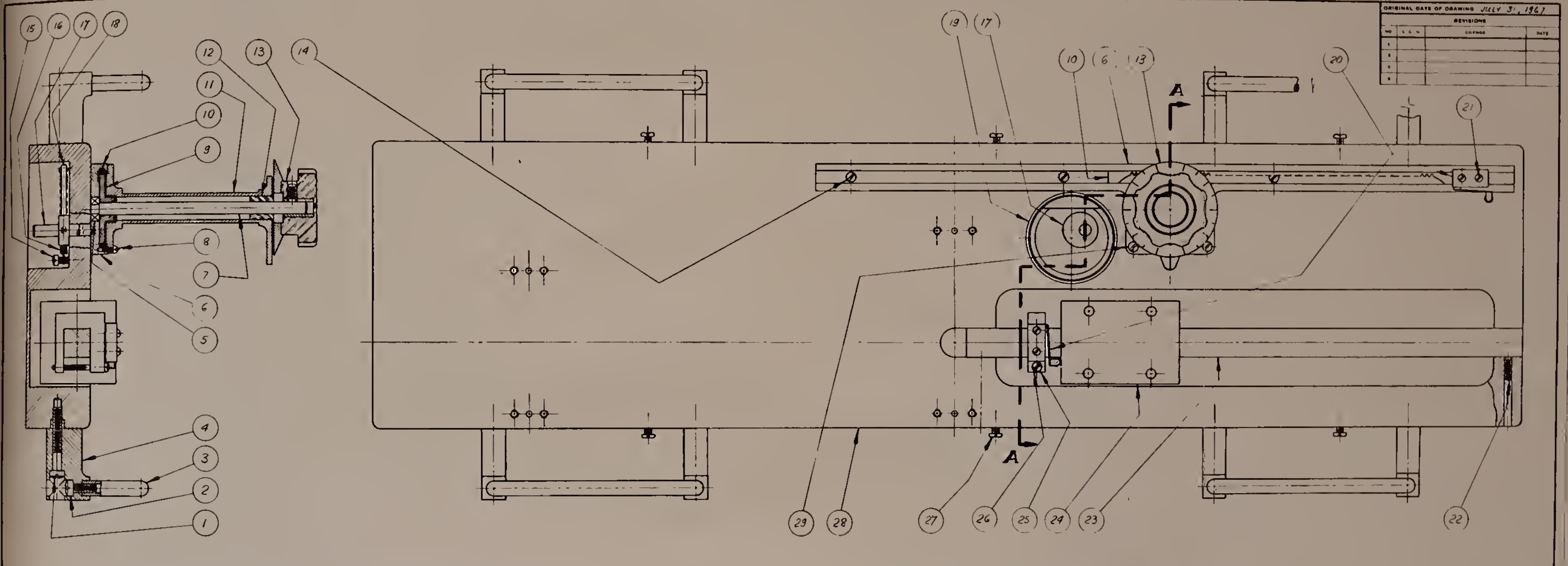
CIRCULAR WAVEGUIDE
BELOW CUT OFF ATTENUATOR

FOR NOMINAL 30 MHz OPERATION

MODEL VII	TYPE	SCALE AS NOTED
DIMENSIONS IN INCHES (Unless otherwise specified)	DRAFTSMAN VICTOR LECINSKI	A.L. SCHUSTER
TOLERANCES (Unless otherwise specified) DECIMALS ±.005 FRACTIONS ±.010 ANGLES ±½°	PROJECT ENGR D H RUSSELL	PROJECT ENGR
	SUBMITTED BY CHIEF SEC.	
DO NOT SCALE THIS PRINT	EXAMINED BY CHIEF ENGINEER	
DIV. SEC. 252/21 — THIS PRINT ISSUED ☐	APPROVED BY CHIEF DIV.	
	AI -7/153 D	

SHEET 4 OF 13

Figure 27(e).



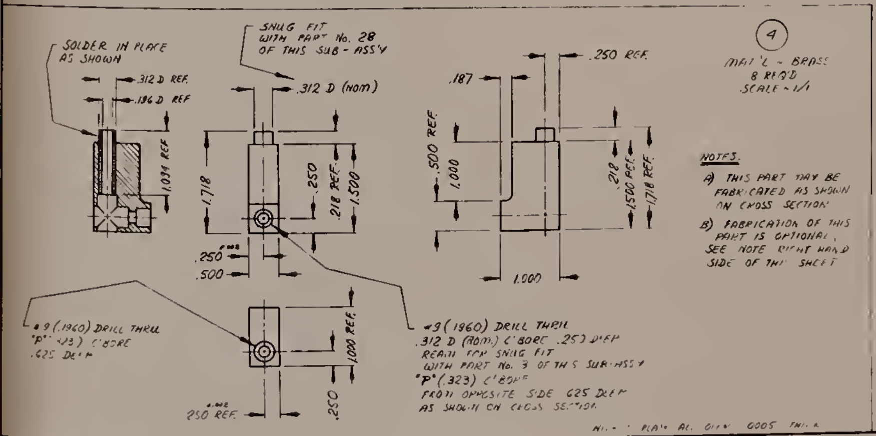
ORIGINAL DATE OF DRAWING JULY 31, 1967

REVISIONS

NO		CHANGE	DATE
1			
2			
3			
4			

SUB-ASSY: ATTENUATOR BASE

SCALE ~ 1/1



④
MAT'L – BRASS
8 REQ'D
SCALE ~ 1/1

NOTES.

A) THIS PART MAY BE FABRICATED AS SHOWN ON CROSS SECTION

B) FABRICATION OF THIS PART IS OPTIONAL, SEE NOTE RIGHT HAND SIDE OF THIS SHEET

*•) PARTS No. 30 NOT INDICATED ON THE ABOVE DRAWING
– THEY SERVE FOR FASTENING OF PART No. 18 TO PART No. 17 (1 REQ'D) AND OF PART No. 19 TO PART No. 18 (2 REQ'D)

LIST OF PARTS

* STOCK ITEMS

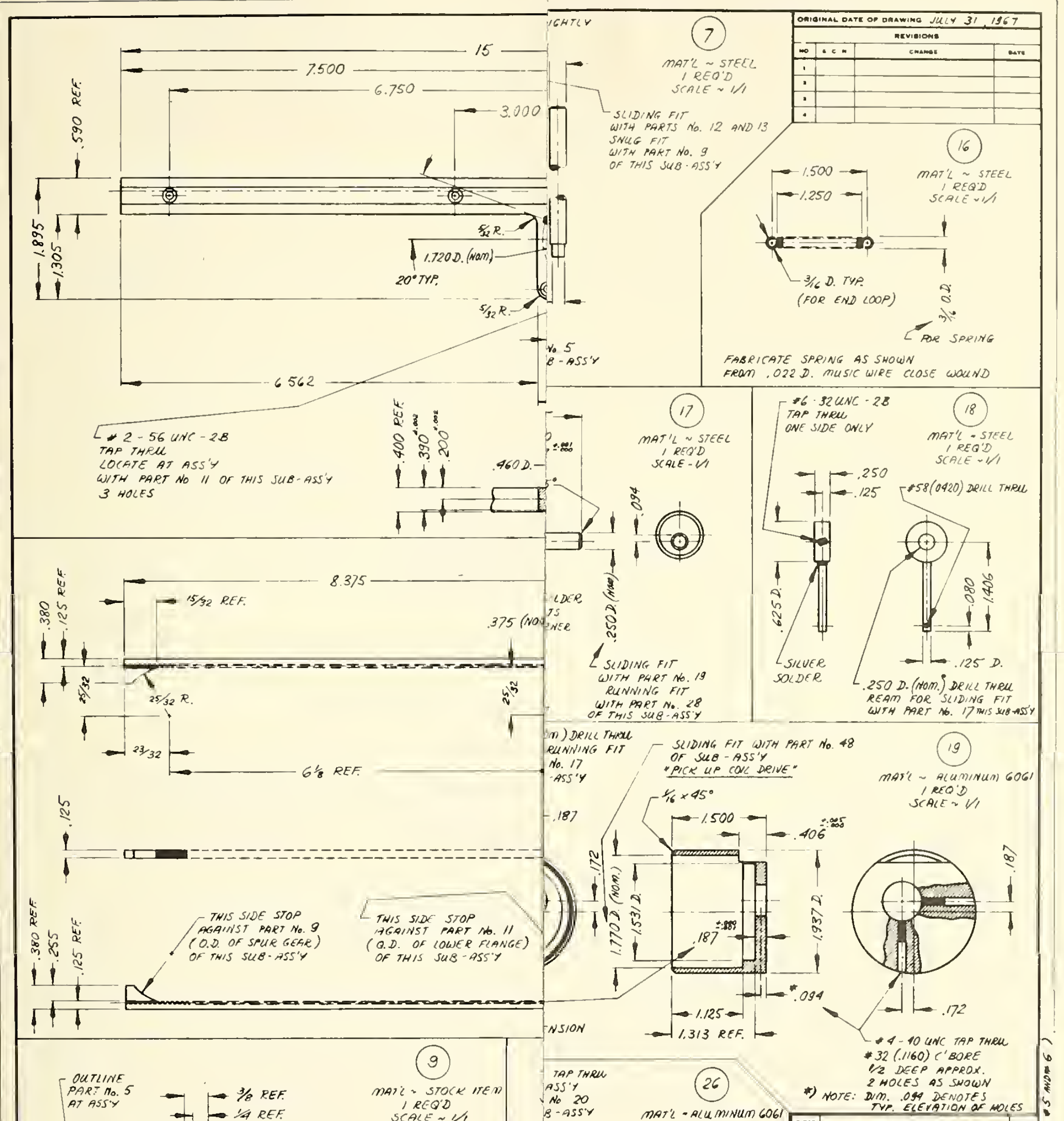
PART No.	NOMENCLATURE	No. REQ'D	PART No.	NOMENCLATURE	No. REQ'D
•30	STEEL SET SCREW, #4-40 UNC, 3/8 LONG, FLAT POINT	3	*15	STEEL SCREW, #6-32 UNC FILLISTER HEAD 1/2 LONG	1
*29	BRASS SCREW, #4-40 UNC, BINDING HEAD, 1/2 LONG	2	*14	BRASS SCREW #4-40 UNC BINDING HD. 3/8 LONG	4
28	BASE MAT'L – MEEHANITE	1	*13	COMMERCIAL KNOB (BAKELITE) WITH 0-10 DIAL 1/4 D SHAFT HOLE	1
*27	BRASS SCREW, #6-32 UNC BINDING HEAD, 1/4 LONG	6	12	BUSHING MAT'L – TEFLON	1
26	MICROSWITCH SUPPORT MAT'L – BRASS	1	11	GEAR COVER MAT'L – BRASS	1
*25	STEEL SCREW #4-40 UNC FILLISTER HEAD, 1¼ LONG	1	*10	BRASS RACK GEAR, 48 PITCH, 14½° P.A., BOSTON CAT. No. G 586 2 FT LONG	1
*24	SQUARE HOUSING W/BEARING GIBS AND WICKS THOMPSON SERIES BUS 625 B	1	*9	BRASS SPUR GEAR 48 PITCH 1.500 P.D., 14½° P.A. BOSTON CAT. No. G 146	1
*23	SQUARE SHAFT THOMPSON SERIES SNG 625, 12" LG	1	*8	BRASS SCREW #2-56 UNC, ROUND HEAD, 1/4 LONG	3
*22	STEEL SET SCREW #8-32 UNC 1/2 LONG FLAT POINT	2	7	SHAFT MAT'L – STEEL	1
*21	BRASS SCREW, #2-56 UNC ROUND HEAD, 3/8 LONG	4	6	GEAR HOUSING MAT'L – BRASS	1
*20	MICRO-SWITCH MICRO 1SM1-T, 8-63 L4 WITH ACTIVATING ARM 25-5	2	*5	BALL BEARING .500 O.D. [illegible] NEW DEPARTURE # 77R3	1
19	MOTOR SUPPORT MAT'L – 6061 ALUMINUM	1	4	HANDLE EXTENSION MAT'L – BRASS	8
18	LEVER MAT'L – STEEL	1	*3	COMMERCIAL CHASSIS HANDLE [illegible] HEIGHT #10-32 UNF TAPPED HOLES, BRASS	4
17	CAM MAT'L – STEEL	1	*2	BRASS SCREW #10-32 UNF FILLISTER HEAD 1/2 LONG	8
16	SPRING MAT'L – STEEL	1	*1	BRASS SCREW #10-32 UNF FILLISTER HEAD 1¼ LONG	8

NOTE: ITEMS No. 1, 2, 3 AND 4 ARE OPTIONAL (USED FOR TRANSPORTATION ONLY)

NOMENCLATURE
NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER COLORADO 80302
CIRCULAR WAVEGUIDE BELOW CUT OFF ATTENUATOR
FOR NOMINAL 30 MHz OPERATION
MODEL VII
SCALE AS NOTED
DRAFTSMAN [illegible] A.L. SINUSTER
PROJECT ENGR D.H. RUSSELL
THIS PRINT ISSUED
252 /21
AI-7/153 D
SHEET 4 OF 13

SUB-ASSY · ATTENUATOR BASE (SHEETS #4, #5 AND #6)

Figure 27(e).



ORIGINAL DATE OF DRAWING JULY 31, 1967
REVISIONS
NO
E C N
CHANGE
DATE
7
MAT'L ~ STEEL
1 REQ'D
SCALE ~ 1/1
15
7.500
6.750
3.000
.590 REF.
1.895
1.305
5/32 R.
1.720 D. (NOM.)
20° TYP.
5/32 R.
SLIDING FIT WITH PARTS No. 12 AND 13
SNUG FIT WITH PART No. 9 OF THIS SUB-ASS'Y
No. 5
B-ASS'Y
6.562
2-56 UNC-2B TAP THRU LOCATE AT ASS'Y WITH PART No 11 OF THIS SUB-ASS'Y 3 HOLES
16
MAT'L ~ STEEL
1 REQ'D
SCALE ~ 1/1
1.500
1.250
3/16 D. TYP. (FOR END LOOP)
3/16 O.D. FOR SPRING
FABRICATE SPRING AS SHOWN FROM .022 D. MUSIC WIRE CLOSE WOUND
.400 REF.
.390
.200
.460 D.
17
MAT'L ~ STEEL
1 REQ'D
SCALE ~ 1/1
.094
.250 D. (NOM.)
SLIDING FIT WITH PART No. 19
RUNNING FIT WITH PART No. 28 OF THIS SUB-ASS'Y
18
MAT'L ~ STEEL
1 REQ'D
SCALE ~ 1/1
#6-32 UNC-2B TAP THRU ONE SIDE ONLY
.250
.125
#58 (.0420) DRILL THRU
.625 D.
.080
1.406
SILVER SOLDER
.125 D.
.250 D. (NOM.) DRILL THRU REAM FOR SLIDING FIT WITH PART No. 17 THIS SUB-ASS'Y
8.375
15/32 REF.
.380
.125 REF.
.375 (NOM.)
25/32
25/32 R.
25/32
23/32
6 1/8 REF.
.125
.380 REF.
.255
.125 REF.
THIS SIDE STOP AGAINST PART No. 9 (O.D. OF SPUR GEAR) OF THIS SUB-ASS'Y
THIS SIDE STOP AGAINST PART No. 11 (O.D. OF LOWER FLANGE) OF THIS SUB-ASS'Y
m) DRILL THRU RUNNING FIT No. 17 -ASS'Y
.187
SLIDING FIT WITH PART No. 48 OF SUB-ASS'Y "PICK UP COIL DRIVE"
1/16 x 45°
1.500
.406
.172
1.770 D. (NOM.)
1.531 D.
.187
1.937 D.
.094
1.125
1.313 REF.
ENSION
19
MAT'L ~ ALUMINUM 6061
1 REQ'D
SCALE ~ 1/1
.187
.172
4-40 UNC TAP THRU
32 (.1160) C'BORE 1/2 DEEP APPROX.
2 HOLES AS SHOWN
*) NOTE: DIM. .094 DENOTES TYP. ELEVATION OF HOLES
9
MAT'L ~ STOCK ITEM
1 REQ'D
SCALE ~ 1/1
OUTLINE PART No. 5 AT ASS'Y
3/8 REF.
1/4 REF.
1/8 REF.
5/32
4-40 UNC-2B TAP THRU
1.500 P.D. REF.
.250 D. REF.
1/2 D. REF.
.002 APPROX.
NOTE: MODIFY BOSTON SPUR GEAR AS NOTED ABOVE (TAPPED HOLE) IF NO TAPPED HOLES EXISTING IN STOCK ITEM; SUPPLY STEEL SET SCREW # 4-40 UNC, 1/8 LONG FLAT PT.
TAP THRU ASS'Y No 20 B-ASS'Y
.375
.500
.625
TAP THRU C'BORE THRU AS SHOWN
26
MAT'L ~ ALUMINUM 6061
1 REQ'D
SCALE ~ 1/1
1.218
.937
1.250
.610
1.100
PIECE NO
NOMENCLATURE
NO REQ'D
NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER, COLORADO
CIRCULAR WAVEGUIDE BELOW CUT OFF ATTENUATOR
FOR NOMINAL 30 MHz OPERATION
MODEL VII
TYPE
SCALE AS NOTED
DIMENSIONS IN INCHES (Unless otherwise specified)
TOLERANCES (Unless otherwise specified)
DECIMALS ± .005
FRACTIONS ± 1/64
ANGLES ± 1/2°
DO NOT SCALE THIS PRINT
DRAFTSMAN VICTOR LECINSKI
A.L. SCHULSTER
PROJECT ENGR D.H. RUSSELL
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SUBMITTED BY
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CHIEF DIV.
DIV. SEC. 252/21
THIS PRINT ISSUED
AI-7/153 D
SHEET 5 OF 13
SUB-ASS'Y: ATTENUATOR BASE (SHEETS # 4, # 5 AND # 6)

Figure 27(f).

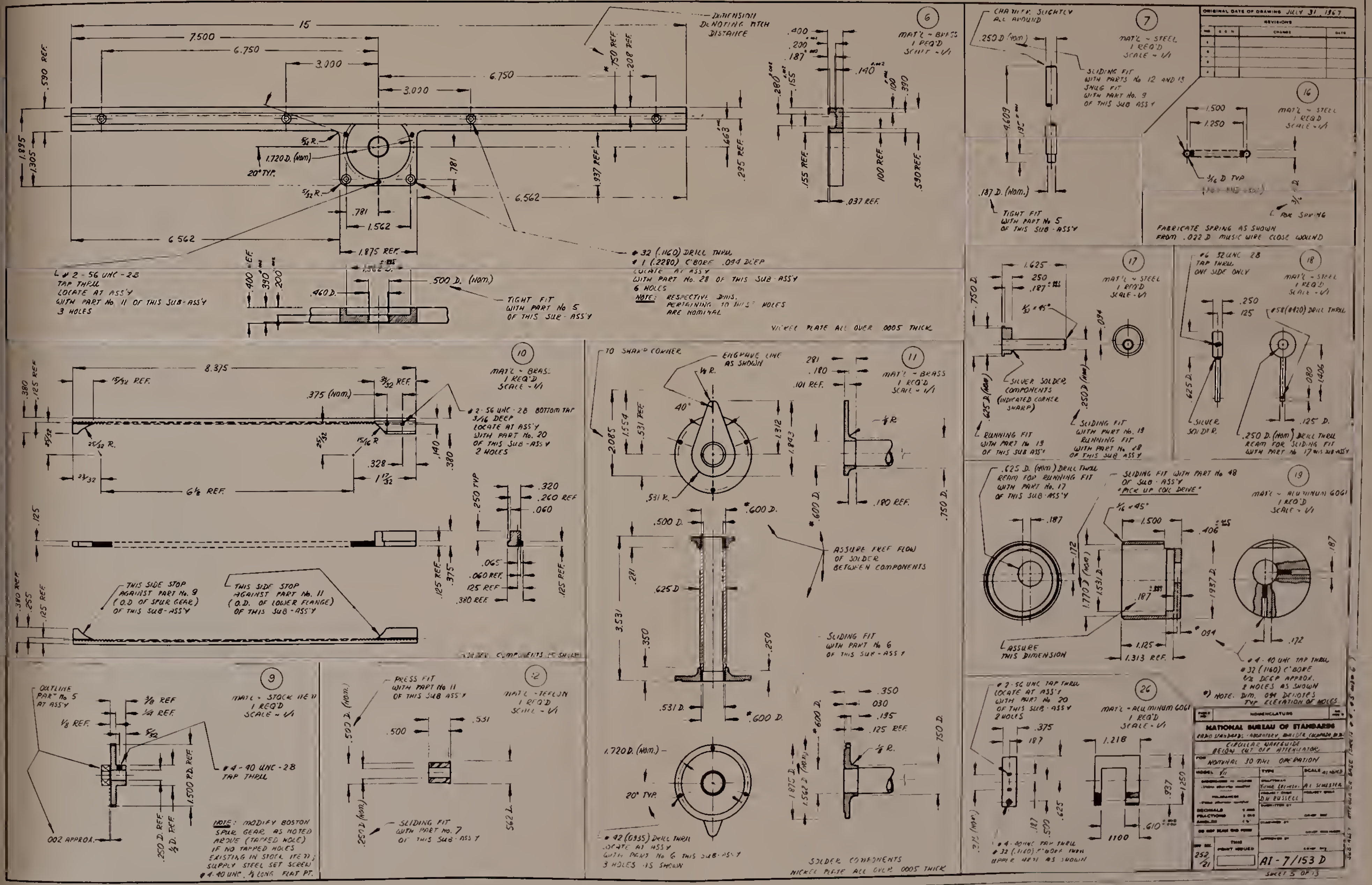
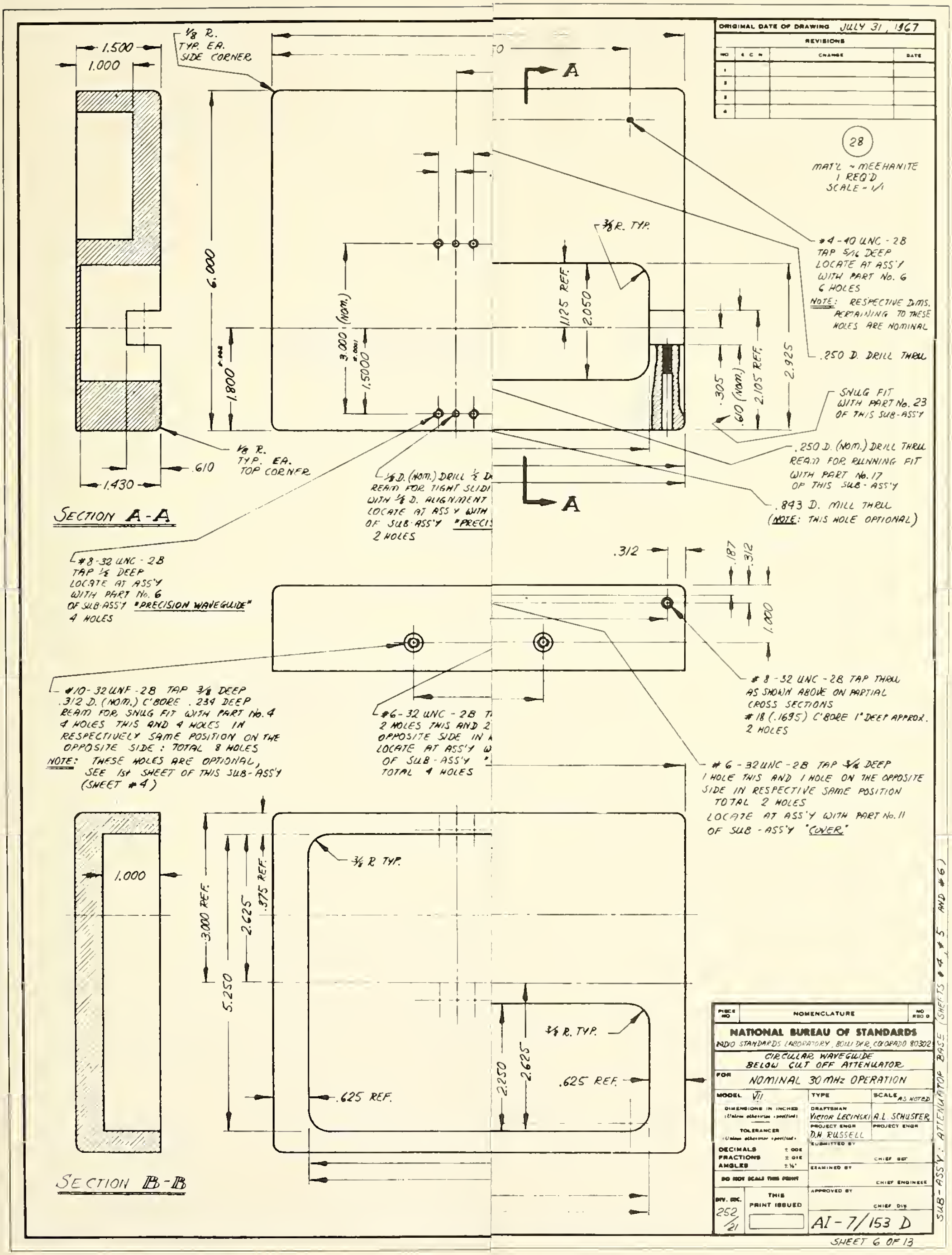

NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER, COLORADO
CIRCULAR WAVEGUIDE BELOW CUT OFF ATTENUATOR
FOR NOMINAL 30 MHz OPERATION
SCALE AS NOTED
AI SCHUSTER
D H RUSSELL
252/21
AI - 7/153 D
SHEET 5 OF 13
ORIGINAL DATE OF DRAWING JULY 31, 1967
REVISIONS
6
MAT'L ~ BRASS
1 REQ'D
SCALE ~ 1/1
DIMENSION DENOTING PITCH DISTANCE
15
7.500
6.750
3.000
3.000
6.562
1.720 D. (Nom)
20° TYP.
5/32 R.
1.875 REF.
1.562
1.562 D.
.500 D. (Nom)
.460 D.
2-56 UNC-2B TAP THRU LOCATE AT ASS'Y WITH PART No. 11 OF THIS SUB-ASS'Y 3 HOLES
TIGHT FIT WITH PART No 5 OF THIS SUB-ASS'Y
32 (.1160) DRILL THRU # 1 (.2280) C'BORE .094 DEEP LOCATE AT ASS'Y WITH PART No. 28 OF THIS SUB-ASS'Y 6 HOLES
NOTE: RESPECTIVE DIMS. PERTAINING TO THIS HOLES ARE NOMINAL
NICKEL PLATE ALL OVER .0005 THICK
7
MAT'L ~ STEEL
1 REQ'D
SCALE ~ 1/1
CHAMFER SLIGHTLY ALL AROUND
.250 D (Nom)
SLIDING FIT WITH PARTS No 12 AND 13 SNUG FIT WITH PART No. 9 OF THIS SUB ASS'Y
.187 D. (Nom.)
TIGHT FIT WITH PART No 5 OF THIS SUB-ASS'Y
16
MAT'L ~ STEEL
1 REQ'D
SCALE ~ 1/1
1.500
1.250
3/16 D TYP
FABRICATE SPRING AS SHOWN FROM .022 D MUSIC WIRE CLOSE WOUND
17
MAT'L ~ STEEL
1 REQ'D
SCALE ~ 1/1
1.625
SILVER SOLDER COMPONENTS (INDICATED CORNER SHARP)
RUNNING FIT WITH PART No 19 OF THIS SUB ASS'Y
SLIDING FIT WITH PART No. 18
RUNNING FIT WITH PART No. 28 OF THIS SUB ASS'Y
18
MAT'L ~ STEEL
1 REQ'D
SCALE ~ 1/1
#6 32 UNC 2B TAP THRU ONE SIDE ONLY
#58 (.0420) DRILL THRU
SILVER SOLDER
.250 D. (Nom) DRILL THRU REAM FOR SLIDING FIT WITH PART No 17 THIS SUB ASS'Y
19
MAT'L ~ ALUMINUM 6061
1 REQ'D
SCALE ~ 1/1
.625 D. (Nom) DRILL THRU REAM FOR RUNNING FIT WITH PART No. 17 OF THIS SUB-ASS'Y
SLIDING FIT WITH PART No 48 OF SUB-ASS'Y "PICK UP COIL DRIVE"
1/16 x 45°
ASSURE THIS DIMENSION
1.313 REF.
4-40 UNC TAP THRU # 32 (.1160) C'BORE 1/2 DEEP APPROX. 2 HOLES AS SHOWN
*) NOTE. DIM. .094 DENOTES TYP ELEVATION OF HOLES
10
MAT'L ~ BRASS
1 REQ'D
SCALE ~ 1/1
8.375
#2-56 UNC-2B BOTTOM TAP 3/16 DEEP LOCATE AT ASS'Y WITH PART No. 20 OF THIS SUB-ASS'Y 2 HOLES
6 1/8 REF.
THIS SIDE STOP AGAINST PART No. 9 (O.D OF SPUR GEAR) OF THIS SUB-ASS'Y
THIS SIDE STOP AGAINST PART No. 11 (O.D. OF LOWER FLANGE) OF THIS SUB-ASS'Y
SOLDER COMPONENTS AS SHOWN
11
MAT'L ~ BRASS
1 REQ'D
SCALE ~ 1/1
TO SHARP CORNER
ENGRAVE LINE AS SHOWN
ASSURE FREE FLOW OF SOLDER BETWEEN COMPONENTS
SLIDING FIT WITH PART No 6 OF THIS SUB-ASS'Y
42 (.0935) DRILL THRU LOCATE AT ASS'Y WITH PART No 6 THIS SUB-ASS'Y 3 HOLES AS SHOWN
SOLDER COMPONENTS
NICKEL PLATE ALL OVER .0005 THICK
9
MAT'L ~ STOCK ITEM
1 REQ'D
SCALE ~ 1/1
OUTLINE PART No 5 AT ASS'Y
#4-40 UNC-2B TAP THRU
1.500 P.D. REF
.002 APPROX.
NOTE: MODIFY BOSTON SPUR GEAR AS NOTED ABOVE (TAPPED HOLE) IF NO TAPPED HOLES EXISTING IN STOCK ITEM; SUPPLY STEEL SET SCREW #4-40 UNC, 1/4 LONG FLAT PT.
12
MAT'L ~ TEFLON
1 REQ'D
SCALE ~ 1/1
PRESS FIT WITH PART No 11 OF THIS SUB ASS'Y
SLIDING FIT WITH PART No. 7 OF THIS SUB ASS'Y
26
MAT'L ~ ALUMINUM 6061
1 REQ'D
SCALE ~ 1/1
2-56 UNC TAP THRU LOCATE AT ASS'Y WITH PART No 20 OF THIS SUB-ASS'Y 2 HOLES
4-40 UNC TAP THRU # 32 (.1160) C'BORE THRU UPPER ITEM AS SHOWN
1.218
.1100

Figure 27(f).


ORIGINAL DATE OF DRAWING JULY 31, 1967
REVISIONS
NO
E C N
CHANGE
DATE
1
2
3
4
28
MAT'L ~ MEEHANITE
1 REQ'D
SCALE ~ 1/1
1.500
1.000
1/8 R.
TYP. EA.
SIDE CORNER
A
6.000
1.800
3.000 (NOM.)
1.5000
1.125 REF.
2.050
3/8 R. TYP.
.305
.610 (NOM.)
2.105 REF.
2.925
#4-40 UNC-2B
TAP 5/16 DEEP
LOCATE AT ASS'Y
WITH PART No. 6
6 HOLES
NOTE: RESPECTIVE DIMS. PERTAINING TO THESE HOLES ARE NOMINAL
.250 D. DRILL THRU
SNUG FIT
WITH PART No. 23
OF THIS SUB-ASS'Y
.250 D. (NOM.) DRILL THRU
REAM FOR RUNNING FIT
WITH PART No. 17
OF THIS SUB-ASS'Y
.843 D. MILL THRU
(NOTE: THIS HOLE OPTIONAL)
1/8 R.
TYP. EA.
TOP CORNER
.610
1.430
SECTION A-A
1/8 D. (NOM.) DRILL 1/2 D
REAM FOR TIGHT SLIDI
WITH 1/8 D. ALIGNMENT
LOCATE AT ASS'Y WITH
OF SUB-ASS'Y "PRECIS
2 HOLES
#8-32 UNC-2B
TAP 1/2 DEEP
LOCATE AT ASS'Y
WITH PART No. 6
OF SUB-ASS'Y "PRECISION WAVEGUIDE"
4 HOLES
.312
.187
.312
1.000
#10-32 UNF-2B TAP 3/8 DEEP
.312 D. (NOM.) C'BORE .234 DEEP
REAM FOR SNUG FIT WITH PART No. 4
4 HOLES THIS AND 4 HOLES IN
RESPECTIVELY SAME POSITION ON THE
OPPOSITE SIDE: TOTAL 8 HOLES
NOTE: THESE HOLES ARE OPTIONAL,
SEE 1st SHEET OF THIS SUB-ASS'Y
(SHEET #4)
#6-32 UNC-2B T
2 HOLES THIS AND 2
OPPOSITE SIDE IN
LOCATE AT ASS'Y W
OF SUB-ASS'Y "
TOTAL 4 HOLES
#8-32 UNC-2B TAP THRU
AS SHOWN ABOVE ON PARTIAL
CROSS SECTIONS
#18 (.1695) C'BORE 1" DEEP APPROX.
2 HOLES
#6-32 UNC-2B TAP 5/16 DEEP
1 HOLE THIS AND 1 HOLE ON THE OPPOSITE
SIDE IN RESPECTIVE SAME POSITION
TOTAL 2 HOLES
LOCATE AT ASS'Y WITH PART No. 11
OF SUB-ASS'Y "COVER"
1.000
3/8 R. TYP.
3.000 REF.
2.625
.375 REF.
5.250
3/8 R. TYP.
2.250
2.625
.625 REF.
.625 REF.
SECTION B-B
PIECE NO
NOMENCLATURE
NO REQ'D
NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER, COLORADO 80302
CIRCULAR WAVEGUIDE
BELOW CUT OFF ATTENUATOR
FOR NOMINAL 30 MHz OPERATION
MODEL VII
TYPE
SCALE AS NOTED
DIMENSIONS IN INCHES (Unless otherwise specified)
TOLERANCES (Unless otherwise specified)
DECIMALS ± .005
FRACTIONS ± .015
ANGLES ± 1/2°
DO NOT SCALE THIS PRINT
DRAFTSMAN
VICTOR LECINSKI
A.L. SCHUSTER
PROJECT ENGR
D.H. RUSSELL
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SUBMITTED BY
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APPROVED BY
CHIEF DIV
DIV. SEC. 252/21
THIS PRINT ISSUED
AI-7/153 D
SHEET 6 OF 13
SUB-ASS'Y: ATTENUATOR BASE (SHEETS #4, #5 AND #6)

Figure 27(g).

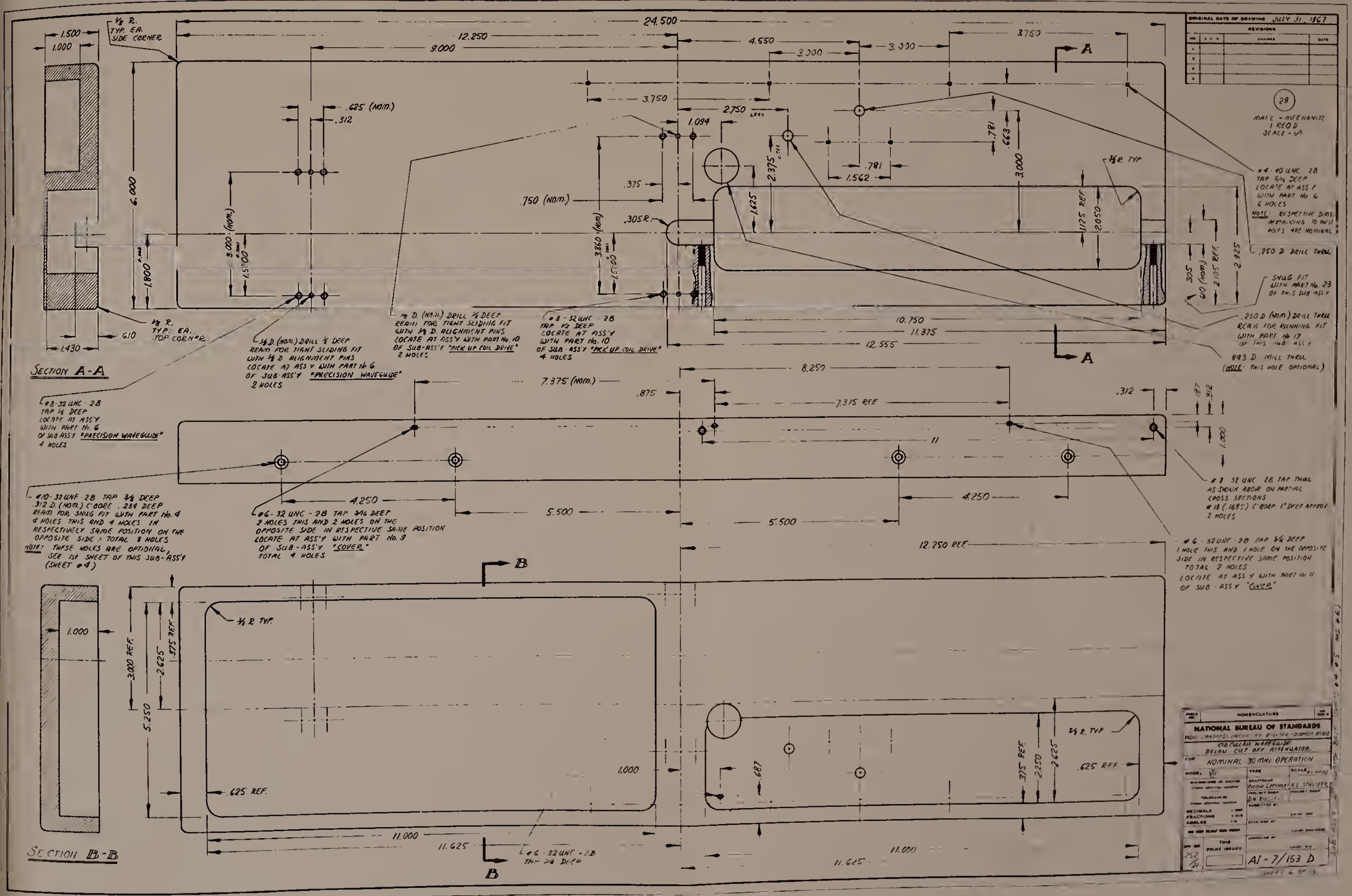
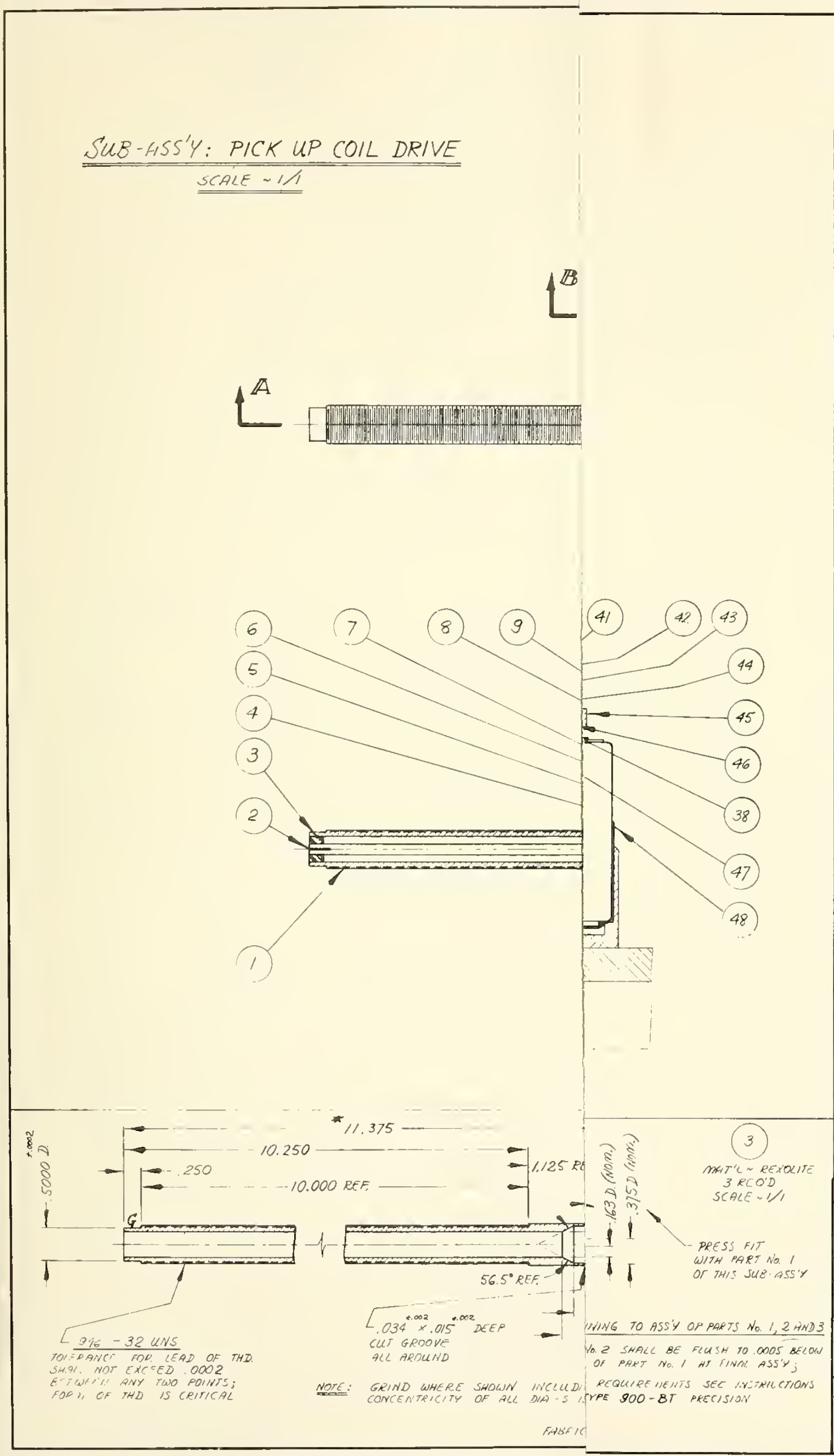

ORIGINAL DATE OF DRAWING JULY 31, 1967
REVISIONS
28
MAT'L = MEEHANITE
1 REQ'D
SCALE - ½
1/8 R. TYP. EA. SIDE CORNER
1/8 R. TYP. EA. TOP CORNER
SECTION A-A
SECTION B-B
A
B
24.500
12.250
9.000
4.550
3.000
3.000
3.750
3.750
2.750
1.094
.625 (NOM.)
.312
.781
.663
1.562
3.000
2.375
1.625
.375
.750 (NOM.)
.305 R.
3.000 (NOM.)
3.860 (NOM.)
1.500
1.800
6.000
1.500
1.000
1.430
.610
1.125 REF.
2.050
1/4 R. TYP.
.305
.610 (NOM.)
2.105 REF.
2.925
10.750
11.375
12.555
8.250
7.375 (NOM.)
7.315 REF.
.875
.312
.187
.912
1.000
4.250
5.500
5.500
4.250
12.250 REF.
3/4 R. TYP.
1.000
3.000 REF.
2.625
.375 REF.
5.250
.625 REF.
11.000
11.625
1.000
.687
.375 REF.
2.250
2.625
.625 REF.
11.000
11.625
#4-40 UNC 28 TAP 5/16 DEEP LOCATE AT ASS'Y WITH PART No 6 6 HOLES
NOTE: RESPECTIVE DIMS. PERTAINING TO THESE HOLES ARE NOMINAL
.250 D DRILL THRU
SNUG FIT WITH PART No 23 OF THIS SUB ASS'Y
.250 D (NOM) DRILL THRU REAM FOR RUNNING FIT WITH PART No 17 OF THIS SUB ASS'Y
.893 D MILL THRU (NOTE: THIS HOLE OPTIONAL)
1/8 D. (NOM.) DRILL 1/2 DEEP REAM FOR TIGHT SLIDING FIT WITH 1/8 D. ALIGNMENT PINS LOCATE AT ASS'Y WITH PART No. 10 OF SUB-ASS'Y "PICK UP COIL DRIVE" 2 HOLES
#8-32 UNC-28 TAP 1/2 DEEP LOCATE AT ASS'Y WITH PART No. 10 OF SUB-ASS'Y "PICK UP COIL DRIVE" 4 HOLES
1/8 D. (NOM.) DRILL 1/2 DEEP REAM FOR TIGHT SLIDING FIT WITH 1/8 D ALIGNMENT PINS LOCATE AT ASS'Y WITH PART No 6 OF SUB-ASS'Y "PRECISION WAVEGUIDE" 2 HOLES
#8-32 UNC-28 TAP 1/2 DEEP LOCATE AT ASS'Y WITH PART No. 6 OF SUB ASS'Y "PRECISION WAVEGUIDE" 4 HOLES
#10-32 UNF-28 TAP 3/4 DEEP .312 D. (NOM.) C'BORE .234 DEEP REAM FOR SNUG FIT WITH PART No. 4 4 HOLES THIS AND 4 HOLES IN RESPECTIVELY SAME POSITION ON THE OPPOSITE SIDE: TOTAL 8 HOLES
NOTE: THESE HOLES ARE OPTIONAL, SEE 1st SHEET OF THIS SUB-ASS'Y (SHEET #4)
#6-32 UNC-28 TAP 5/16 DEEP 2 HOLES THIS AND 2 HOLES ON THE OPPOSITE SIDE IN RESPECTIVE SAME POSITION LOCATE AT ASS'Y WITH PART No. 9 OF SUB-ASS'Y "COVER" TOTAL 4 HOLES
#8-32 UNC-28 TAP THRU AS SHOWN ABOVE ON PARTIAL CROSS SECTIONS #18 (.1695) C'BORE 1" DEEP APPROX 2 HOLES
#6-32 UNC-28 TAP 1/4 DEEP 1 HOLE THIS AND 1 HOLE ON THE OPPOSITE SIDE IN RESPECTIVE SAME POSITION TOTAL 2 HOLES LOCATE AT ASS'Y WITH PART No 11 OF SUB-ASS'Y "COVER"
#6-32 UNC-2B THD 1/4 DEEP
NOMENCLATURE
NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LAB. BOULDER, COLORADO 80302
CIRCULAR WAVEGUIDE BELOW CUT OFF ATTENUATOR
FOR NOMINAL 30 MHz OPERATION
MODEL VII
SCALE AS NOTED
DRAFTSMAN Verna Lechner
R.L. SCHUSTER
D.H. RUSSELL
DECIMALS
FRACTIONS
ANGLES
THIS PRINT ISSUED
252/21
AI-7/153 D
SHEET 6 OF 13

Figure 27(g).



ORIGINAL DATE OF DRAWING JULY 31, 1967

REVISIONS

NO	E C N	CHANGE	DATE
1			

LIST OF PARTS

* STOCK ITEMS

PIECE NO	NOMENCLATURE	NO REQ'D
50	TRIPPER, MICROSWITCH MAT'L ~ ALUMINUM	1
*49	TERMINAL STRIP 8 DBL 2-56-3/16 BINDING HD., 5/8 WIDE × 5/16 THICK	1
*48	MOTOR, EASTERN AIR DEVICES # P 42 QDP - 2	1
47	DRIVE WHEEL MAT'L - ALUMINUM 6061	1
*46	O-RING PARKER # 2 - 111	2
45	DIAL MAT'L ~ ALUMINUM 6061	1
44	KNOB INSULATOR MAT'L ~ NYLON	1
*43	STEEL SET SCREW, # 4-40 UNC, 3/16 LONG, FLAT POINT	1
42	KNOB MAT'L ~ ALUMINUM 6061	1
*41	BEVEL GEAR BOSTON # G - 481Y - G	1
*40	STEEL KEY, 1/16 × 1/16 × 3/4 LONG FLAT	1
*39	BEVEL GEAR BOSTON # G - 481 Y - P	1
*38	STEEL SET SCREW, # 4 - 40 UNC, 1/8 LONG, CONE POINT	4
37	BRACKET MAT'L ~ ALUMINUM 6061	1
*36	BEARING, SLEEVE TYPE, PLAIN BOSTON # B - 46 - 5	1
35	SHAFT EXTENSION, COUNTER MAT'L ~ CRS	1
*34	BRASS SCREW, # 2 - 56 UNC, 5/16 LONG, ROUND HD.	2
33	INDEX PLATE MAT'L ~ ALUMINUM 6061	1
*32	BRASS SCREW, # 4 - 40 UNC, 1/4 LONG, FLAT HD	2
31	SHIMMY MAT'L ~ BRASS (OR COPPER)	2
*30	COUNTER, VEEDER-ROOT # E 114235	1
29	COLLAR MAT'L ~ STEEL	1
28	BEARING, SLEEVE TYPE MAT'L ~ OILITE	1
27	DRIVE SHAFT MAT'L ~ STEEL	1
*26	STEEL KEY, 1/8 × 1/8 × 1/4 LONG	1
*25	HELICAL GEAR BOSTON # H 2460 R	1
*24	HELICAL GEAR BOSTON # H 2418 R	1
23	GEAR HOUSING MAT'L ~ ALUMINUM 6061	1
22	THRUST WASHER MAT'L ~ STEEL	1
*21	STEEL SCREW, # 6 - 32 UNC, 1/2 LONG, HEX. SOCKET HD.	3
20	GUIDE MAT'L ~ MEEHANITE	1
*19	STEEL SCREW, # 4 - 40 UNC, 1/2 LONG HEX. SOCKET HD	4
*18	STEEL SCREW, HEX. SOCKET HD WITH HEX NUT, # 10 - 32 UNF, 2" LONG	4
17	ANTI BACKLASH NUT MAT'L ~ BRASS	1
*16	STEEL SCREW, # 6 - 32 UNC, 3/8 LONG, HEX SOCKET HD.	3
15	RETAINER RING MAT'L ~ ALUMINUM 6061	1
*14	BRASS SCREW, # 2 - 56 UNC, 1/4 LONG, FLAT HD.	6
*13	STEEL SCREW, # 6 - 32 UNC, 3/4 LONG, HEX. SOCKET HD.	2
*12	ALIGNMENT PIN MAT'L ~ .1250 D. DRILL ROD, 1" LG.	2
*11	STEEL SCREW, # 8 - 32 UNC 3/4 LONG, HEX. SOCKET HD	4
10	BEARING HOUSING MAT'L ~ ALUMINUM 6061	1
9	SPACER, MAT'L ~ BRASS	1
*8	SINGLE ROW, ANGULAR CONTACT BEARING ND # OLO 4 (.7874 BORE, 1.6535 O.D., .4724W)	2
7	RETAINER NUT MAT'L ~ BRASS	1
*6	STEEL SET SCREW, # 4 - 40 UNC 3/8 LONG, CONE POINT	2
5	WIPER MAT'L ~ FELT, 1/16 THICK	2
4	THRUST NUT MAT'L ~ PHOSPHOR BRONZE	1
3	DIELECTRIC SPACER MAT'L ~ REXOLITE	3
2	CENTER CONDUCTOR MAT'L ~ BRASS	1
1	MOTION TRANSLATING SCREW MAT'L ~ 58-60 RC STEEL	1

NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER, COLORADO, 80302

CIRCULAR WAVEGUIDE
BELOW CUT OFF ATTENUATOR

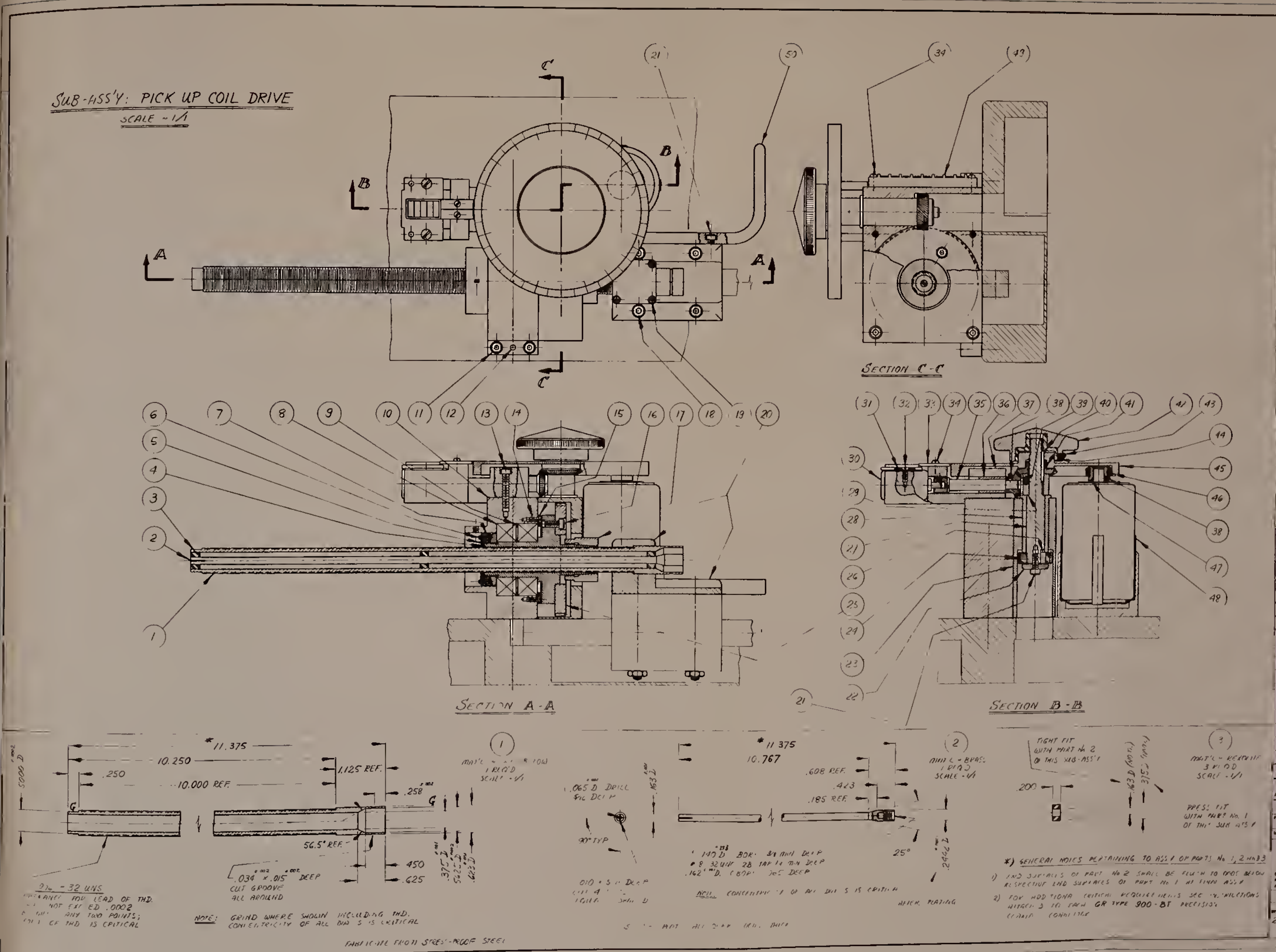
FOR NOMINAL 30 MHz OPERATION

MODEL VI	TYPE	SCALE AS NOTED
DIMENSIONS IN INCHES (Unless otherwise specified)	DRAFTSMAN VICTOR LECINSKI	A L. SCHUSTER
TOLERANCES (Unless otherwise specified) DECIMALS ± .005 FRACTIONS ± .015 ANGLES ± 1/2°	PROJECT ENGR D.H. RUSSELL	PROJECT ENGR
	SUBMITTED BY CHIEF SEC.	
DO NOT SCALE THIS PRINT	EXAMINED BY CHIEF ENGINEER	
DIV. SEC. 252/21	THIS PRINT ISSUED	APPROVED BY CHIEF DIV
		AI - 7/153 D

SHEET 7 OF 13

SUB-ASS'Y. PICK UP COIL DRIVE (SHEETS # 7 # 8 AND # 9)

Figure 27(h).



*) GENERAL NOTES PERTAINING TO ASS'Y OF PARTS No 1, 2 AND 3

1) END SURFACES OF PART No 2 SHALL BE FLUSH TO .005 BELOW RESPECTIVE END SURFACES OF PART No 1 AT FINAL ASS'Y

2) FOR ADDITIONAL CRITICAL REQUIREMENTS SEE SPECIFICATIONS ATTACHED TO EACH GR TYPE 900-BT PRECISION COAXIAL CONNECTOR

ORIGINAL DATE OF DRAWING JULY 31, 1967

REVISIONS

NO	E C N	CHANGE	DATE
1			

LIST OF PARTS

* STOCK ITEMS

PIECE NO	NOMENCLATURE	NO. REQ'D
50	TRIPPER, MICROSWITCH MAT'L - ALUMINUM	1
*49	TEF [illegible] STRIP [illegible] [illegible] WIDE [illegible]	1
*48	MOTOR, EAST PN AP DEVICES #P 42 QDP - 3	1
47	DRIVE WHEEL MAT'L - ALUMINUM 6061	1
*46	O - RING MOYER # 2 - 11	2
45	DIAL MAT'L - ALUMINUM 6061	1
44	KNOB INSULATOR MAT'L - NYLON	1
*43	STEEL SET SCREW # 4 40UNC 1/4 LONG, FLAT POINT	1
42	KNOB MAT'L - ALUMINUM 6061	1
*41	BEVEL GEAR BOSTON # G - 481Y G	1
*40	STEEL KEY 1/16 x 1/16 x 1/4 LONG FLAT	1
*39	BEVEL GEAR BOSTON # G - 481 Y - P	1
*38	STEEL SET SCREW, # 4 40 UNC 1/8 LONG CONE POINT	4
37	BRACKET MAT'L - ALUMINUM 6061	1
*36	BEARING SLEEVE TYPE MAIN BOSTON # B - 46 5	1
35	SHAFT EXTENSION COUNTER MAT'L - CRS	1
*34	BRASS SCREW # 2 56 UNC 3/16 LONG ROUND HD.	2
33	INDEX PLATE MAT'L - ALUMINUM 6061	1
*32	BRASS SCREW # 4 - 40 UNC 1/4 LONG FLAT HD	2
31	SHIMMY MAT'L - BRASS (IN CORNER)	2
*30	COUNTER VEEDER-ROOT # E - 4235	1
29	COLLAR MAT'L - STEEL	1
28	BEARING SLEEVE TYPE MAT'L - OILITE	1
27	DRIVE SHAFT MAT'L - STEEL	1
*26	STEEL KEY 1/8 x 1/8 x 1/2 LONG	1
*25	HELICAL GEAR BOSTON # H 2460 R	1
*24	HELICAL GEAR BOSTON # H 2418 R	1
23	GEAR HOUSING MAT'L - ALUMINUM 6061	1
22	THRUST WASHER MAT'L STEEL	1
*21	STEEL SCREW # 6 32 UNC 1/2 LONG HEX SOCKET HD	3
20	GUIDE MAT'L - MECHANITE	1
*19	STEEL SCREW # 4 40 UNC 1/2 LONG HEX SOCKET HD	4
*18	STEEL SCREW HEX SOCKET HD WITH HEX NUT, # 10 32 UNF, 1" LONG	4
17	ANTIBACKLASH NUT MAT'L - BRASS	1
*16	STEEL SCREW # 6 32 UNC 1/2 LONG HEX SOCKET HD	3
15	RETAINER RING MAT'L - ALUMINUM 6061	1
*14	BRASS SCREW # 2 56 UNC 1/4 LONG, FLAT HD	6
*13	STEEL SCREW # 6 32 UNC 3/8 LONG HEX SOCKET HD	2
*12	ALIGNMENT PIN MAT'L - .1250 D DOWEL ROD 1" LG	2
*11	STEEL SCREW # 8 32 UNC 3/4 LONG HEX SOCKET HD	4
10	BEARING HOUSING MAT'L - ALUMINUM 6061	1
9	SPACER MAT'L - BRASS	1
*8	SINGLE ROW ANGULAR CONTACT BALL BRG # 010 4 (.3750 BORE, 1.6535 OD, [illegible])	2
7	RETAINER NUT MAT'L - BRASS	1
*6	STEEL SET SCREW # 4 40UNC 3/16 LONG CONE POINT	2
5	WIPER MAT'L - FELT, 1/16 THICK	2
4	THRUST NUT MAT'L - PHOSPHOR BRONZE	1
3	DIELECTRIC SPACER MAT'L - REXOLITE	3
2	CENTER CONDUCTOR MAT'L - BRASS	1
1	MOTION TRANSLATING SCREW MAT'L - 58 [illegible] STEEL	1

(SHEETS # 7, # 8 AND # 9)

NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY BOULDER, COLORADO 80302

CIRCULAR WAVEGUIDE
BELOW CUT OFF ATTENUATOR

FOR NOMINAL 30 MHz OPERATION

MODEL | TYPE | SCALE AS NOTED

DIMENSIONS IN INCHES (Unless otherwise specified)

TOLERANCES (Unless otherwise specified)
DECIMALS ± .005
FRACTIONS ± .015
ANGLES ± 1/2°

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DRAFTSMAN: [illegible] | A L SCHASTER
PROJECT ENGR: D H RUSSELL
SUBMITTED BY: CHIEF SEC
CHECKED BY: CHIEF ENGINEER
APPROVED BY: CHIEF DIV

INV NO 252/21

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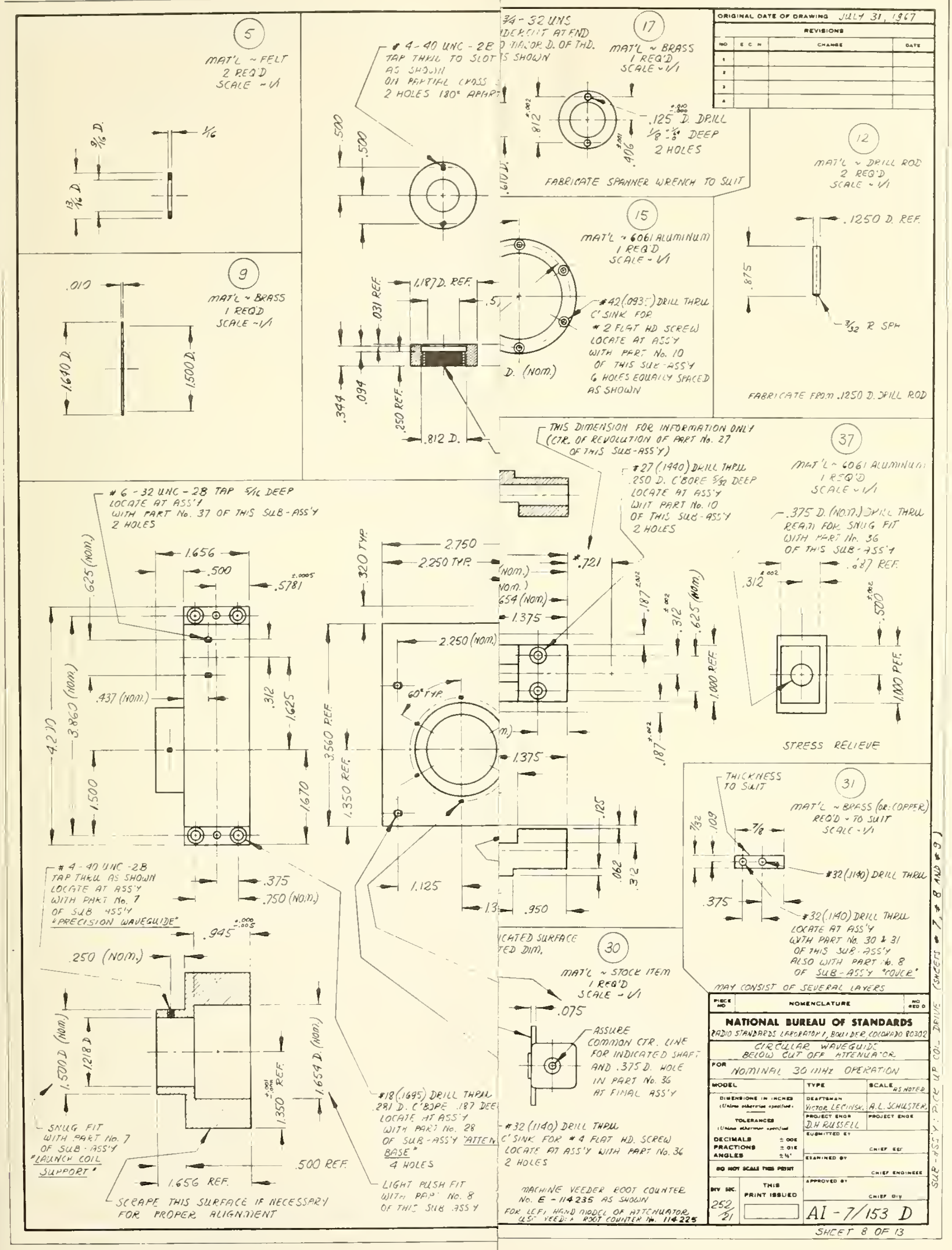
SHEET 7 OF 13

Figure 27(h).


ORIGINAL DATE OF DRAWING JULY 31, 1967
REVISIONS
NO
E C N
CHANGE
DATE
5
MAT'L ~ FELT
2 REQ'D
SCALE ~ 1/1
1/16
9/16 D.
13/16 D
9
.010
MAT'L ~ BRASS
1 REQD
SCALE ~ 1/1
1.640 D.
1.500 D.
4-40 UNC-2B
TAP THRU TO SLOT AS SHOWN
ON PARTIAL CROSS
2 HOLES 180° APART
.500
.500
1.187 D. REF.
.031 REF.
.344
.094
.250 REF.
.812 D.
3/4 - 32 UNS
UNDERCUT AT END
DIA. OR D. OF THD.
AS SHOWN
17
MAT'L ~ BRASS
1 REQ'D
SCALE ~ 1/1
.812
.406
.125 D. DRILL
1/8 DEEP
2 HOLES
FABRICATE SPANNER WRENCH TO SUIT
15
MAT'L ~ 6061 ALUMINUM
1 REQ'D
SCALE ~ 1/1
#42 (.0935) DRILL THRU
C' SINK FOR
2 FLAT HD SCREW
LOCATE AT ASS'Y
WITH PART No. 10
OF THIS SUB-ASS'Y
6 HOLES EQUALLY SPACED
AS SHOWN
D. (NOM.)
12
MAT'L ~ DRILL ROD
2 REQ'D
SCALE ~ 1/1
.1250 D. REF.
.875
3/32 R SPH
FABRICATE FROM .1250 D. DRILL ROD
THIS DIMENSION FOR INFORMATION ONLY
(CTR. OF REVOLUTION OF PART No. 27
OF THIS SUB-ASS'Y)
#27 (.1440) DRILL THRU
.250 D. C'BORE 5/32 DEEP
LOCATE AT ASS'Y
WITH PART No. 10
OF THIS SUB-ASS'Y
2 HOLES
37
MAT'L ~ 6061 ALUMINUM
1 REQ'D
SCALE ~ 1/1
.375 D. (NOM.) DRILL THRU
REAM FOR SNUG FIT
WITH PART No. 36
OF THIS SUB-ASS'Y
.687 REF.
.312
.500
1.000 REF.
STRESS RELIEVE
6-32 UNC-2B TAP 5/16 DEEP
LOCATE AT ASS'Y
WITH PART No. 37 OF THIS SUB-ASS'Y
2 HOLES
1.656
.500
.5781
.625 (NOM.)
4.210
3.860 (NOM.)
.437 (NOM.)
.312
1.625
1.500
1.670
.320 TYP.
2.750
2.250 TYP.
2.250 (NOM.)
60° TYP.
3.560 REF.
1.350 REF.
1.125
.721
(NOM.)
(NOM.)
.654 (NOM.)
1.375
1.375
.187
.312
.625 (NOM.)
1.000 REF.
.187
.125
.062
.312
.950
4-40 UNC-2B
TAP THRU AS SHOWN
LOCATE AT ASS'Y
WITH PART No. 7
OF SUB ASS'Y
"PRECISION WAVEGUIDE"
.375
.750 (NOM.)
.945
.250 (NOM.)
1.500 D (NOM.)
1.218 D
1.350 REF.
1.654 D. (NOM.)
SNUG FIT
WITH PART No. 7
OF SUB-ASS'Y
"LAUNCH COIL SUPPORT"
.500 REF.
1.656 REF.
SCRAPE THIS SURFACE IF NECESSARY
FOR PROPER ALIGNMENT
#18 (.1695) DRILL THRU
.281 D. C'BORE .187 DEEP
LOCATE AT ASS'Y
WITH PART No. 28
OF SUB-ASS'Y "ATTEN BASE"
4 HOLES
LIGHT PUSH FIT
WITH PART No. 8
OF THIS SUB ASS'Y
INDICATED SURFACE
INDICATED DIM.
30
MAT'L ~ STOCK ITEM
1 REQ'D
SCALE ~ 1/1
.075
ASSURE
COMMON CTR. LINE
FOR INDICATED SHAFT
AND .375 D. HOLE
IN PART No. 36
AT FINAL ASS'Y
#32 (.1140) DRILL THRU
C' SINK FOR # 4 FLAT HD. SCREW
LOCATE AT ASS'Y WITH PART No. 36
2 HOLES
MACHINE VEEDER ROOT COUNTER
No. E - 114235 AS SHOWN
FOR LEFT HAND MODEL OF ATTENUATOR
USE VEEDER ROOT COUNTER No. 114225
THICKNESS TO SUIT
31
MAT'L ~ BRASS (OR: COPPER)
REQ'D ~ TO SUIT
SCALE ~ 1/1
7/32
.109
7/8
.375
#32 (.1140) DRILL THRU
#32 (.1140) DRILL THRU
LOCATE AT ASS'Y
WITH PART No. 30 & 31
OF THIS SUB-ASS'Y
ALSO WITH PART No. 8
OF SUB-ASS'Y "COUPLER"
MAY CONSIST OF SEVERAL LAYERS
PIECE NO
NOMENCLATURE
NO REQ'D
NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER, COLORADO 80302
CIRCULAR WAVEGUIDE
BELOW CUT OFF ATTENUATOR
FOR NOMINAL 30 MHz OPERATION
MODEL
TYPE
SCALE AS NOTED
DIMENSIONS IN INCHES (Unless otherwise specified)
TOLERANCES (Unless otherwise specified)
DECIMALS ± .005
FRACTIONS ± .015
ANGLES ± 1/2°
DO NOT SCALE THIS PRINT
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A.L. SCHUSTER
PROJECT ENGR D.H. RUSSELL
PROJECT ENGR
SUBMITTED BY
CHIEF ENGR
EXAMINED BY
CHIEF ENGINEER
APPROVED BY
CHIEF DIV
DIV. SEC. 252/21
THIS PRINT ISSUED
AI - 7/153 D
SHEET 8 OF 13
SUB-ASS'Y: PICK UP COIL DRIVE (SHEETS # 7, # 8 AND # 9)

Figure 27(i).

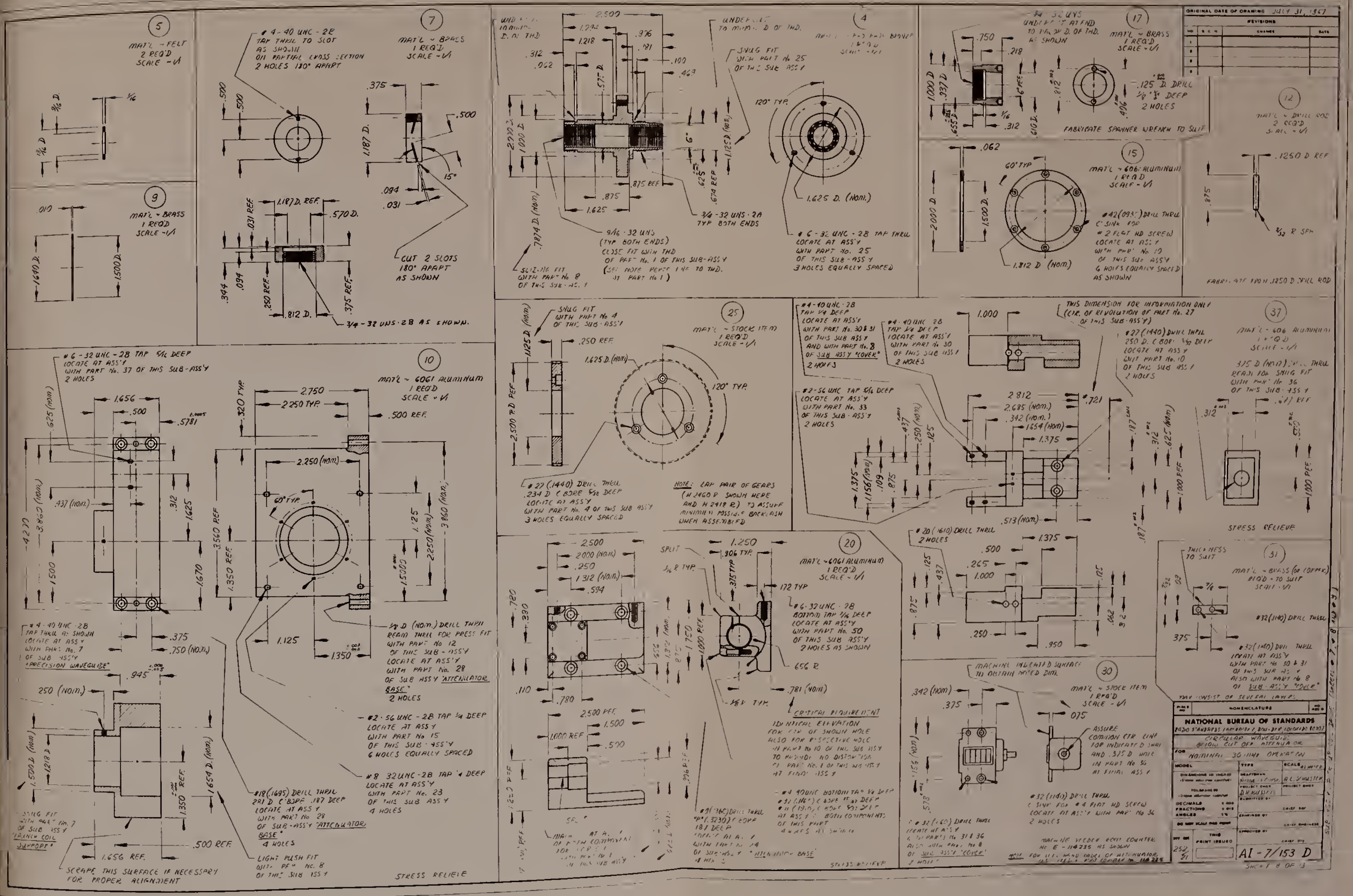
ORIGINAL DATE OF DRAWING JULY 31, 1957
REVISIONS
5
MAT'L ~ FELT
2 REQ'D
SCALE ~ 1/1
9
MAT'L ~ BRASS
1 REQ'D
SCALE ~ 1/1
#4-40 UNC-2B TAP THRU TO SLOT AS SHOWN ON PARTIAL CROSS SECTION 2 HOLES 180° APART
7
MAT'L ~ BRASS
1 REQ'D
SCALE ~ 1/1
CUT 2 SLOTS 180° APART AS SHOWN
3/4-32 UNS-2B AS SHOWN.
4
9/16-32 UNS (TYP BOTH ENDS) CLOSE FIT WITH THD OF PART No. 1 OF THIS SUB-ASS'Y
SLIDING FIT WITH PART No 8 OF THIS SUB-ASS'Y
3/4-32 UNS-2A TYP BOTH ENDS
SNUG FIT WITH PART No. 25 OF THIS SUB ASS'Y
120° TYP.
1.625 D. (NOM.)
#6-32 UNC-2B TAP THRU LOCATE AT ASS'Y WITH PART No. 25 OF THIS SUB-ASS'Y 3 HOLES EQUALLY SPACED
17
MAT'L ~ BRASS
1 REQ'D
SCALE ~ 1/1
.125 D DRILL 1/8 DEEP 2 HOLES
FABRICATE SPANNER WRENCH TO SUIT
15
MAT'L ~ 6061 ALUMINUM
1 REQ'D
SCALE ~ 1/1
#42(.0935) DRILL THRU C'SINK FOR #2 FLAT HD SCREW LOCATE AT ASS'Y WITH PART No 10 OF THIS SUB ASS'Y 6 HOLES EQUALLY SPACED AS SHOWN
1.812 D (NOM)
12
MAT'L ~ DRILL ROD
2 REQ'D
SCALE ~ 1/1
.1250 D REF
FABRICATE FROM .1250 D DRILL ROD
10
MAT'L ~ 6061 ALUMINUM
1 REQ'D
SCALE ~ 1/1
#6-32 UNC-2B TAP 5/16 DEEP LOCATE AT ASS'Y WITH PART No. 37 OF THIS SUB-ASS'Y 2 HOLES
#4-40 UNC-2B TAP THRU AS SHOWN LOCATE AT ASS'Y WITH PART No. 7 OF SUB ASS'Y "PRECISION WAVEGUIDE"
SNUG FIT WITH PART No. 7 OF SUB ASS'Y "FRENCH COIL SUPPORT"
SCRAPE THIS SURFACE IF NECESSARY FOR PROPER ALIGNMENT
#18(.1695) DRILL THRU .281 D C'BORE .187 DEEP LOCATE AT ASS'Y WITH PART No 28 OF SUB-ASS'Y "ATTENUATOR BASE" 4 HOLES
LIGHT PUSH FIT WITH PART No. 8 OF THIS SUB ASS'Y
1/8 D (NOM.) DRILL THRU REAM THRU FOR PRESS FIT WITH PART No 12 OF THIS SUB-ASS'Y LOCATE AT ASS'Y WITH PART No. 28 OF SUB ASS'Y ATTENUATOR BASE 2 HOLES
#2-56 UNC-2B TAP 1/4 DEEP LOCATE AT ASS'Y WITH PART No 15 OF THIS SUB-ASS'Y 6 HOLES EQUALLY SPACED
#8-32 UNC-2B TAP 1/4 DEEP LOCATE AT ASS'Y WITH PART No. 23 OF THIS SUB ASS'Y 4 HOLES
STRESS RELIEVE
25
MAT'L ~ STOCK ITEM
1 REQ'D
SCALE ~ 1/1
SNUG FIT WITH PART No 4 OF THIS SUB-ASS'Y
#27(.1440) DRILL THRU .234 D C'BORE 5/32 DEEP LOCATE AT ASS'Y WITH PART No. 4 OF THIS SUB ASS'Y 3 HOLES EQUALLY SPACED
NOTE: LAP PAIR OF GEARS (H 2460 P SHOWN HERE AND H 2418 R) TO ASSURE MINIMUM POSSIBLE BACKLASH WHEN ASSEMBLED
20
MAT'L ~ 6061 ALUMINUM
1 REQ'D
SCALE ~ 1/1
SPLIT
#6-32 UNC-2B BOTTOM TAP 3/8 DEEP LOCATE AT ASS'Y WITH PART No. 50 OF THIS SUB ASS'Y 2 HOLES AS SHOWN
CRITICAL REQUIREMENT
STRESS RELIEVE
#4-40 UNC-2B TAP 1/4 DEEP LOCATE AT ASS'Y WITH PART No. 30 & 31 OF THIS SUB ASS'Y AND WITH PART No. 8 OF SUB ASS'Y "COVER" 2 HOLES
#4-40 UNC-2B TAP 1/4 DEEP LOCATE AT ASS'Y WITH PART No. 30 OF THIS SUB ASS'Y 2 HOLES
#2-56 UNC TAP 5/16 DEEP LOCATE AT ASS'Y WITH PART No. 33 OF THIS SUB-ASS'Y 2 HOLES
THIS DIMENSION FOR INFORMATION ONLY (CIR. OF REVOLUTION OF PART No. 27 OF THIS SUB-ASS'Y)
#27(.1440) DRILL THRU .250 D. C'BORE 5/32 DEEP LOCATE AT ASS'Y WITH PART No. 10 OF THIS SUB ASS'Y 2 HOLES
#20(.1610) DRILL THRU 2 HOLES
37
MAT'L ~ 606 ALUMINUM
1 REQ'D
SCALE ~ 1/1
.375 D (NOM.) DRILL THRU REAM FOR SNUG FIT WITH PART No 36 OF THIS SUB ASS'Y
STRESS RELIEVE
31
MAT'L ~ BRASS (or COPPER)
REQ'D ~ TO SUIT
SCALE ~ 1/1
THICKNESS TO SUIT
#32(.1160) DRILL THRU
#32(.1160) DRILL THRU LOCATE AT ASS'Y WITH PART No 30 & 31 OF THIS SUB ASS'Y ALSO WITH PART No 8 OF SUB-ASS'Y "COVER"
MAY CONSIST OF SEVERAL LAYERS
30
MAT'L ~ STOCK ITEM
1 REQ'D
SCALE ~ 1/1
MACHINE INDICATED SURFACE TO OBTAIN NOTED DIM.
ASSURE COMMON CTR LINE FOR INDICATED SHAFT AND .375 D HOLE IN PART No 36 AT FINAL ASS'Y
#32(.1160) DRILL THRU C'SINK FOR #4 FLAT HD SCREW LOCATE AT ASS'Y WITH PART No 36 2 HOLES
MACHINE VEEDER ROOT COUNTER No E-114235 AS SHOWN
NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER, COLORADO
CIRCULAR WAVEGUIDE BELOW CUT OFF ATTENUATOR
FOR NOMINAL 30 MHz OPERATION
MODEL
TYPE
SCALE AS NOTED
DRAFTSMAN
A. L. SHUSTER
PROJECT ENGR
D. H. RUSSELL
SUBMITTED BY
CHIEF SEC
EXAMINED BY
CHIEF ENGINEER
APPROVED BY
CHIEF DIV
DECIMALS
FRACTIONS
ANGLES
DO NOT SCALE THIS PRINT
THIS PRINT ISSUED
252/21
AI-7/153 D
SHEET 8 OF 13

Figure 27(i).

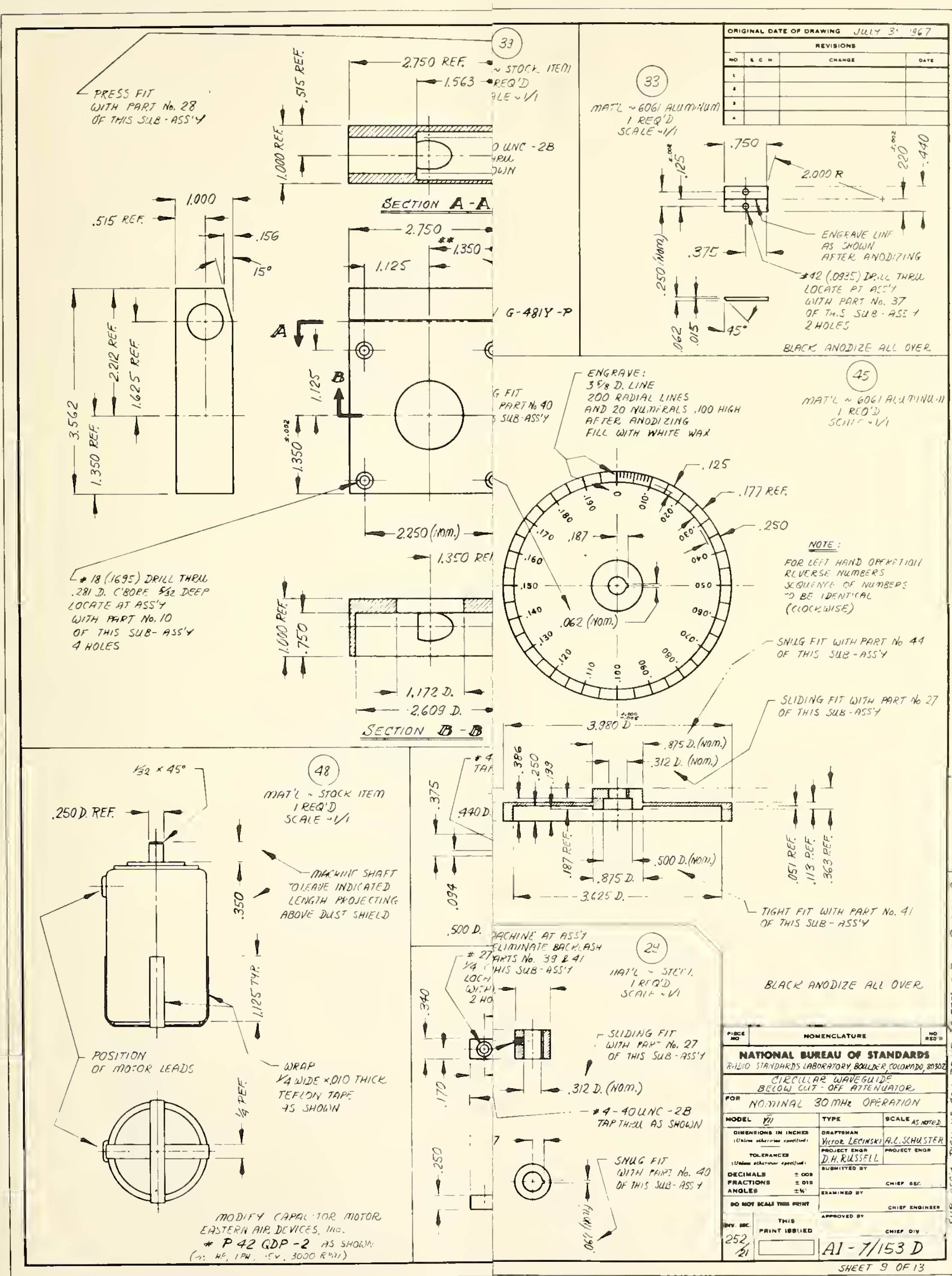

ORIGINAL DATE OF DRAWING JULY 3 1967
REVISIONS
NO
E C N
CHANGE
DATE
PRESS FIT WITH PART No. 28 OF THIS SUB-ASS'Y
2.750 REF.
1.563
.515 REF.
1.000 REF.
STOCK ITEM
REQ'D
ALE ~ 1/1
UNC -2B
SECTION A-A
1.000
.515 REF.
.156
15°
3.562
2.212 REF.
1.625 REF.
1.350 REF.
2.750
1.350
1.125
G-481Y-P
1.350
2.250 (nom.)
1.350 REF.
18 (.1695) DRILL THRU .281 D. C'BORE 5/32 DEEP LOCATE AT ASS'Y WITH PART No. 10 OF THIS SUB-ASS'Y 4 HOLES
G FIT PART No. 40 SUB-ASS'Y
1.000 REF.
.750
1.172 D.
2.609 D.
SECTION B-B
33
MAT'L ~ 6061 ALUMINUM 1 REQ'D SCALE ~ 1/1
.750
2.000 R
.125
.220
.440
ENGRAVE LINE AS SHOWN AFTER ANODIZING
.375
.250 (Nom.)
#42 (.0935) DRILL THRU LOCATE AT ASS'Y WITH PART No. 37 OF THIS SUB-ASS'Y 2 HOLES
.062
.015
45°
BLACK ANODIZE ALL OVER
ENGRAVE: 3 5/8 D. LINE 200 RADIAL LINES AND 20 NUMERALS .100 HIGH AFTER ANODIZING FILL WITH WHITE WAX
45
MAT'L ~ 6061 ALUMINUM 1 REQ'D SCALE ~ 1/1
.125
.177 REF.
.250
.187
.062 (Nom.)
NOTE: FOR LEFT HAND OPERATION REVERSE NUMBERS SEQUENCE OF NUMBERS TO BE IDENTICAL (CLOCKWISE)
SNUG FIT WITH PART No. 44 OF THIS SUB-ASS'Y
SLIDING FIT WITH PART No. 27 OF THIS SUB-ASS'Y
3.980 D
.875 D. (Nom.)
.312 D. (Nom.)
.386
.250
.199
.187 REF.
.500 D. (Nom.)
.875 D.
3.625 D.
.051 REF.
.113 REF.
.363 REF.
TIGHT FIT WITH PART No. 41 OF THIS SUB-ASS'Y
48
MAT'L ~ STOCK ITEM 1 REQ'D SCALE ~ 1/1
1/32 × 45°
.250 D. REF.
MACHINE SHAFT TO LEAVE INDICATED LENGTH PROJECTING ABOVE DUST SHIELD
.350
1.125 TYP.
POSITION OF MOTOR LEADS
WRAP 1/4 WIDE × .010 THICK TEFLON TAPE AS SHOWN
1/4 REF.
MODIFY CAPACITOR MOTOR EASTERN AIR DEVICES, Inc. # P 42 GDP-2 AS SHOWN
.375
.440 D.
.094
.500 D.
MACHINE AT ASS'Y ELIMINATE BACKLASH PARTS No. 39 & 41 THIS SUB-ASS'Y
27
1/4
2 HO
29
MAT'L ~ STEEL 1 REQ'D SCALE ~ 1/1
.340
.170
SLIDING FIT WITH PART No. 27 OF THIS SUB-ASS'Y
.312 D. (Nom.)
4-40 UNC-2B TAP THRU AS SHOWN
.250
SNUG FIT WITH PART No. 40 OF THIS SUB-ASS'Y
(Nom.) .190
BLACK ANODIZE ALL OVER
PIECE NO
NOMENCLATURE
NO REQ'D
NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER, COLORADO, 80302
CIRCULAR WAVEGUIDE BELOW CUT-OFF ATTENUATOR
FOR NOMINAL 30 MHz OPERATION
MODEL VII
TYPE
SCALE AS NOTED
DIMENSIONS IN INCHES (Unless otherwise specified)
DRAFTSMAN Victor Lecinski
A.L. SCHUSTER
TOLERANCES (Unless otherwise specified)
PROJECT ENGR D.H. RUSSELL
PROJECT ENGR
DECIMALS ± .005
FRACTIONS ± .015
ANGLES ± 1/2°
SUBMITTED BY
CHIEF SEC.
EXAMINED BY
DO NOT SCALE THIS PRINT
CHIEF ENGINEER
APPROVED BY
DIV. SEC. 252.21
THIS PRINT ISSUED
CHIEF DIV.
AI - 7/153 D
SHEET 9 OF 13
SUB-ASS'Y: PICK UP COIL DRIVE (SHEETS # 7, # 8 AND # 9)

Figure 27(i).

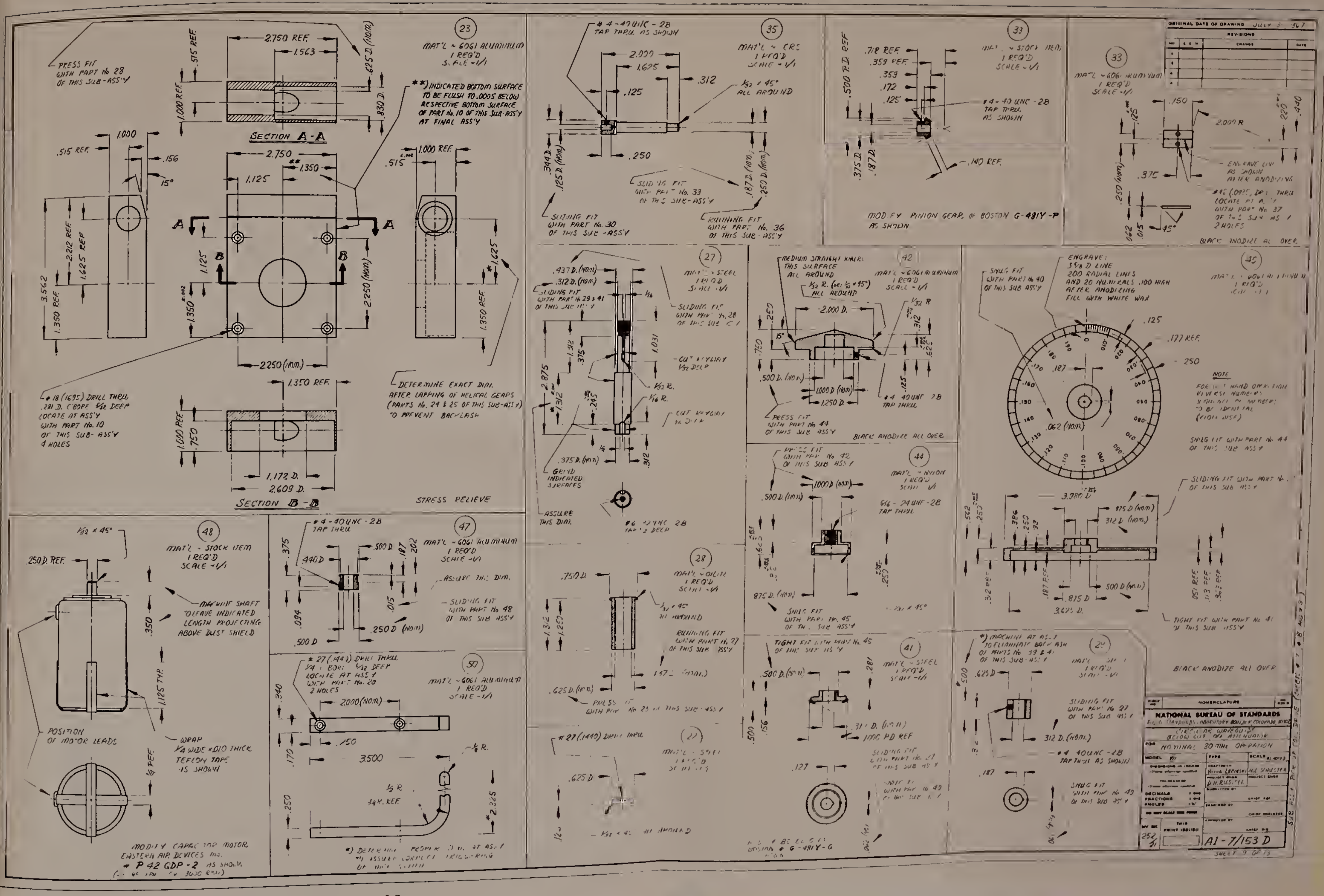
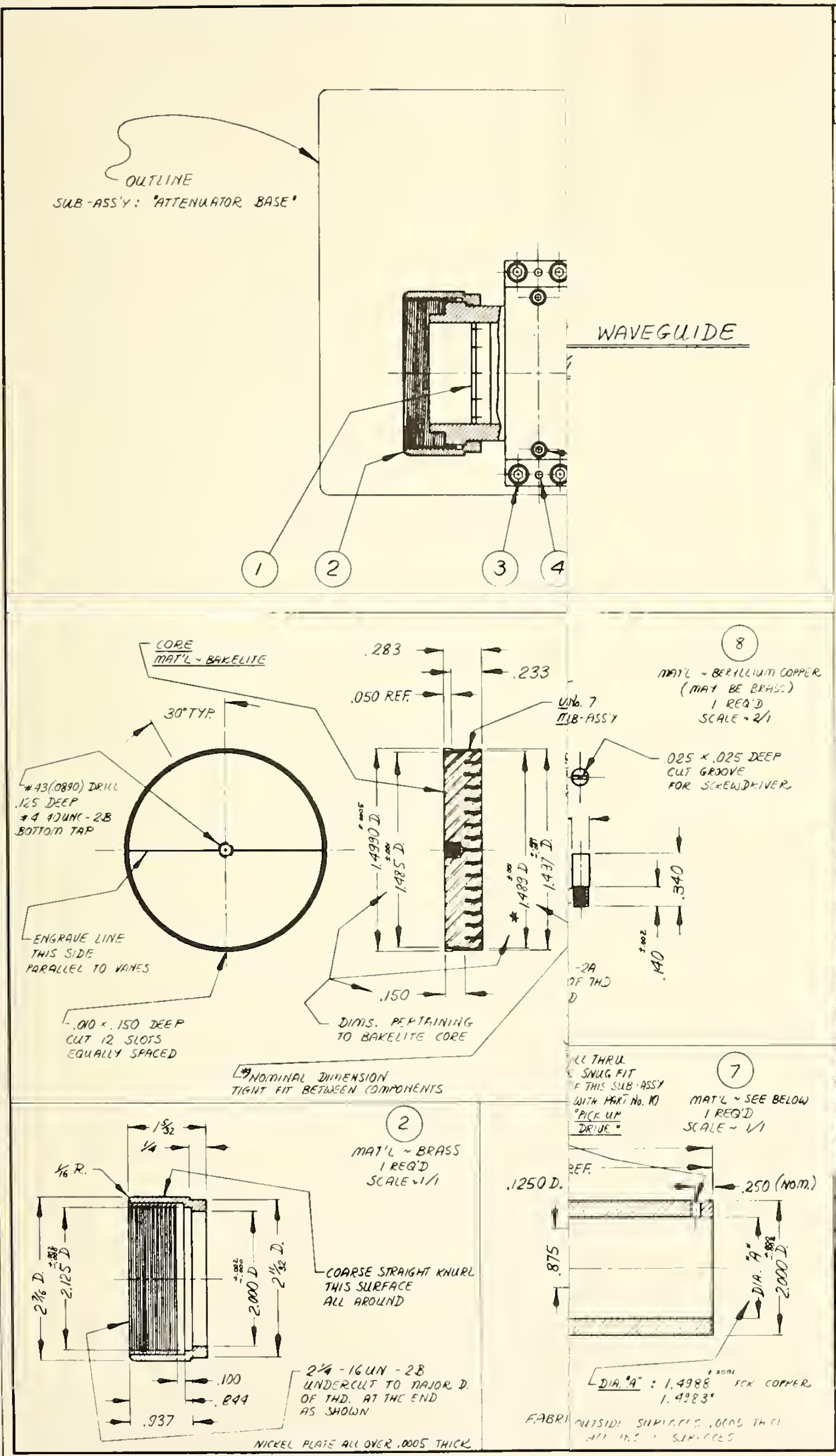

23
MAT'L ~ 6061 ALUMINUM
1 REQ'D
SCALE ~1/1
PRESS FIT WITH PART No. 28 OF THIS SUB-ASS'Y
SECTION A-A
SECTION B-B
**) INDICATED BOTTOM SURFACE TO BE FLUSH TO .0005 BELOW RESPECTIVE BOTTOM SURFACE OF PART No. 10 OF THIS SUB-ASS'Y AT FINAL ASS'Y
#18 (.1695) DRILL THRU .281 D. C'BORE 5/32 DEEP LOCATE AT ASS'Y WITH PART No. 10 OF THIS SUB-ASS'Y 4 HOLES
DETERMINE EXACT DIM. AFTER LAPPING OF HELICAL GEARS (PARTS No. 24 & 25 OF THIS SUB-ASS'Y) TO PREVENT BACKLASH
STRESS RELIEVE
35
MAT'L ~ CRS
1 REQ'D
SCALE ~ 1/1
#4-40 UNC-28 TAP THRU AS SHOWN
1/32 × 45° ALL AROUND
SLIDING FIT WITH PART No. 33 OF THIS SUB-ASS'Y
SLIDING FIT WITH PART No. 30 OF THIS SUB-ASS'Y
RUNNING FIT WITH PART No. 36 OF THIS SUB-ASS'Y
33
MAT'L ~ STOCK ITEM
1 REQ'D
SCALE ~ 1/1
#4-40 UNC-28 TAP THRU AS SHOWN
MODIFY PINION GEAR OF BOSTON G-481Y-P AS SHOWN
33
MAT'L ~ 6061 ALUMINUM
1 REQ'D
SCALE ~1/1
ENGRAVE LINE AS SHOWN AFTER ANODIZING
#42 (.0935) DR. THRU LOCATE AT ASS'Y WITH PART No. 37 OF THIS SUB ASS'Y 2 HOLES
BLACK ANODIZE ALL OVER
27
MAT'L ~ STEEL
1 REQ'D
SCALE ~1/1
SLIDING FIT WITH PART No. 28 & 41 OF THIS SUB ASS'Y
SLIDING FIT WITH PART No. 28 OF THIS SUB ASS'Y
CUT KEYWAY 1/32 DEEP
GRIND INDICATED SURFACES
ASSURE THIS DIM.
#6-40 UNC-28 TAP 1/2 DEEP
42
MAT'L ~ 6061 ALUMINUM
1 REQ'D
SCALE ~1/1
MEDIUM STRAIGHT KNURL THIS SURFACE ALL AROUND
1/32 R. (or 1/32 × 45°) ALL AROUND
PRESS FIT WITH PART No. 44 OF THIS SUB ASS'Y
#4-40 UNC-28 TAP THRU
BLACK ANODIZE ALL OVER
45
MAT'L ~ 6061 ALUMINUM
1 REQ'D
SCALE ~1/1
SNUG FIT WITH PART No. 40 OF THIS SUB ASS'Y
ENGRAVE: 3 5/8 D LINE 200 RADIAL LINES AND 20 NUMERALS .100 HIGH AFTER ANODIZING FILL WITH WHITE WAX
SNUG FIT WITH PART No. 44 OF THIS SUB ASS'Y
SLIDING FIT WITH PART No. OF THIS SUB ASS'Y
TIGHT FIT WITH PART No. 41 OF THIS SUB ASS'Y
BLACK ANODIZE ALL OVER
44
MAT'L ~ NYLON
1 REQ'D
SCALE ~1/1
PRESS FIT WITH PART No. 42 OF THIS SUB ASS'Y
5/16-24 UNF-28 TAP THRU
SNUG FIT WITH PART No. 45 OF THIS SUB ASS'Y
48
MAT'L ~ STOCK ITEM
1 REQ'D
SCALE ~1/1
MACHINE SHAFT TO LEAVE INDICATED LENGTH PROJECTING ABOVE DUST SHIELD
POSITION OF MOTOR LEADS
WRAP 1/4 WIDE × .010 THICK TEFLON TAPE AS SHOWN
MODIFY CAPACITOR MOTOR EASTERN AIR DEVICES INC. # P 42 GDP-2 AS SHOWN
47
MAT'L ~ 6061 ALUMINUM
1 REQ'D
SCALE ~1/1
#4-40 UNC-28 TAP THRU
ASSURE THIS DIM.
SLIDING FIT WITH PART No. 48 OF THIS SUB ASS'Y
50
MAT'L ~ 6061 ALUMINUM
1 REQ'D
SCALE ~1/1
#27 (.1440) DRILL THRU 1/4 C'BORE 5/32 DEEP LOCATE AT ASS'Y WITH PART No. 20 2 HOLES
*) DETERMINE PROPER DIM. AT ASS'Y TO ASSURE CORRECT TRIGGERING OF MICRO SWITCH
28
MAT'L ~ DELRIN
1 REQ'D
SCALE ~1/1
1/32 × 45° ALL AROUND
RUNNING FIT WITH PART No. 27 OF THIS SUB ASS'Y
PRESS FIT WITH PART No. 25 OF THIS SUB ASS'Y
#27 (.1440) DRILL THRU
MAT'L ~ STEEL
1 REQ'D
1/32 × 45° ALL AROUND
41
MAT'L ~ STEEL
1 REQ'D
SCALE ~1/1
TIGHT FIT WITH PART No. 45 OF THIS SUB ASS'Y
100 PD REF
SLIDING FIT WITH PART No. 27 OF THIS SUB ASS'Y
SNUG FIT WITH PART No. 49 OF THIS SUB ASS'Y
BOSTON # G-481Y-G
24
MAT'L ~ STEEL
1 REQ'D
SCALE ~1/1
*) MACHINE AT ASS'Y TO ELIMINATE BACKLASH OF PARTS No. 39 & 41 OF THIS SUB ASS'Y
SLIDING FIT WITH PART No. 27 OF THIS SUB ASS'Y
#4-40 UNC-28 TAP THRU AS SHOWN
SNUG FIT WITH PART No. 40 OF THIS SUB ASS'Y
ORIGINAL DATE OF DRAWING JULY 3 1967
REVISIONS
NOMENCLATURE
NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY BOULDER COLORADO
CIRCULAR WAVEGUIDE BELOW CUT OFF ATTENUATOR
FOR NOMINAL 30 MHz OPERATION
MODEL VII
SCALE AS NOTED
DRAFTSMAN
H.E. SHUSTER
PROJECT ENGR
D.H. RUSSELL
DECIMALS
FRACTIONS
ANGLES
DO NOT SCALE THIS PRINT
THIS PRINT ISSUED
252/21
AI-7/153 D
SHEET 9 OF 13
SUB ASS'Y PICK UP COIL DRIVE

Figure 27(i).

ORIGINAL DATE OF DRAWING JULY 3, 1967

REVISIONS			
NO	E C N	CHANGE	DATE
1			
2			
3			
4			



LIST OF PARTS

* STOCK ITEMS

PIECE NO	NOMENCLATURE	NO REQ'D
8	SCREW MAT'L ~ BERYLLIUM COPPER OR BRASS	1
1	WAVEGUIDE MAT'L ~ COPPER OR BRASS	1
6	SUPPORT WITH COVER MAT'L ~ 6061 ALUMINUM	1
*5	BRASS SCREW, #6-32 UNC, FILLISTER HEAD, 1 1/8 LONG	2
*4	ALIGNMENT PIN MAT'L ~ .1250 D. STEEL DRILL ROD	2
*3	BRASS SCREW, #8-32 UNC, FILLISTER HEAD, 3/4 LONG	4
2	NUT MAT'L ~ BRASS	1
1	MODE FILTER MAT'L ~ BRASS & BAKELITE	1

NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER, COLORADO, 80302

CIRCULAR WAVEGUIDE
BELOW CUT OFF ATTENUATOR

FOR NOMINAL 30 MHz OPERATION

MODEL VII
TYPE
SCALE AS NOTED

DIMENSIONS IN INCHES (Unless otherwise specified)
TOLERANCES (Unless otherwise specified)
DECIMALS ± .005
FRACTIONS ± .010
ANGLES ± ½°
DO NOT SCALE THIS PRINT

DRAFTSMAN VICTOR LEPINSKI
A L SCHUSTER
PROJECT ENGR D.H. RUSSELL
PROJECT ENGR
SUBMITTED BY
CHIEF SEC
EXAMINED BY
CHIEF ENGINEER
APPROVED BY
CHIEF DIV

DIV SEC 252 21
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SHEET 10 OF 13

SUB-ASS'Y: PRECISION WAVEGUIDE (SHEET # 10)

Figure 27(k).

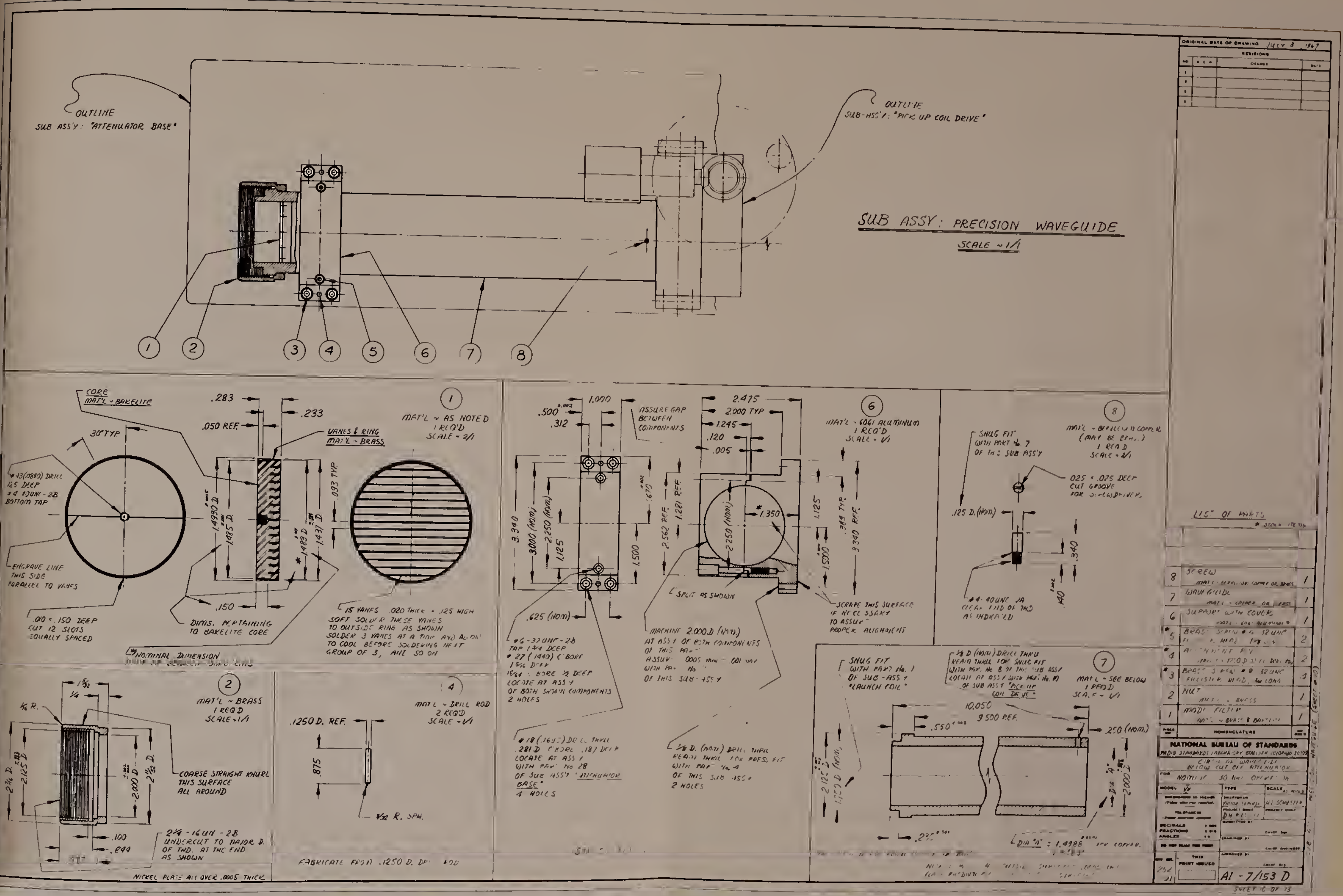
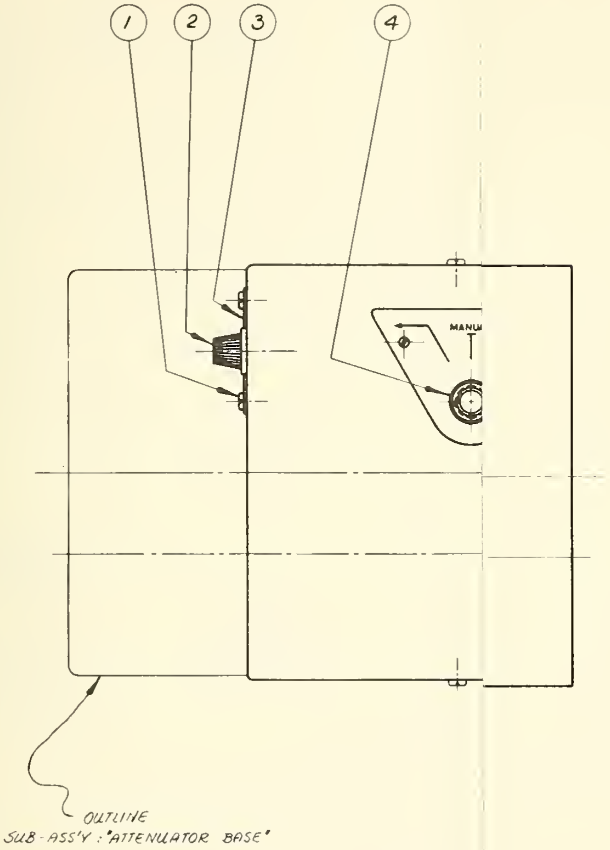

OUTLINE
SUB-ASS'Y: "ATTENUATOR BASE"
OUTLINE
SUB-ASS'Y: "PICK UP COIL DRIVE"
SUB ASSY: PRECISION WAVEGUIDE
SCALE ~ 1/1
1
2
3
4
5
6
7
8
CORE
MAT'L ~ BAKELITE
30° TYP.
#43(.0890) DRILL
1/2 DEEP
#4 40UNC-2B
BOTTOM TAP
ENGRAVE LINE
THIS SIDE
PARALLEL TO VANES
.010 × .150 DEEP
CUT 12 SLOTS
EQUALLY SPACED
.283
.233
.050 REF.
VANES & RING
MAT'L ~ BRASS
1.4990 D
1.485 D
1.489 D
1.437 D
.093 TYP
.150
DIMS. PERTAINING
TO BAKELITE CORE
*NOMINAL DIMENSION
1
MAT'L ~ AS NOTED
1 REQ'D
SCALE ~ 2/1
15 VANES .020 THICK × .125 HIGH
SOFT SOLDER THESE VANES
TO OUTSIDE RING AS SHOWN
SOLDER 3 VANES AT A TIME AND ALLOW
TO COOL BEFORE SOLDERING NEXT
GROUP OF 3, AND SO ON
2
MAT'L ~ BRASS
1 REQ'D
SCALE ~ 1/1
1/16 R.
1 5/32
1/4
2 1/4 D.
2.125 D
2.000 D
2 1/8 D.
COARSE STRAIGHT KNURL
THIS SURFACE
ALL AROUND
.100
.244
2 1/4 - 16UN - 2B
UNDERCUT TO MAJOR D.
OF THD. AT THE END
AS SHOWN
NICKEL PLATE ALL OVER .0005 THICK
4
MAT'L ~ DRILL ROD
2 REQ'D
SCALE ~ 1/1
.1250 D. REF.
.875
1/32 R. SPH.
FABRICATE FROM .1250 D. DRILL ROD
.500
.312
1.000
ASSURE GAP
BETWEEN
COMPONENTS
3.340
3.000 (NOM.)
2.250 (NOM.)
1.125
.670
1.500
.625 (NOM.)
#6-32UNC-2B
TAP 1/4 DEEP
#27 (.1440) C'BORE
1 1/16 DEEP
15/64 : BORE 1/2 DEEP
LOCATE AT ASS'Y
OF BOTH SHOWN COMPONENTS
2 HOLES
#18 (.1695) DRILL THRU
.281 D C'BORE .187 DEEP
LOCATE AT ASS'Y
WITH PART No 28
OF SUB ASS'Y "ATTENUATOR BASE"
4 HOLES
6
MAT'L ~ 6061 ALUMINUM
1 REQ'D
SCALE ~ 1/1
2.475
2.000 TYP
1.245
.120
.005
2.562 REF.
1.281 REF.
*1.350
2.250 (NOM.)
.125
.389 TYP.
3.340 REF.
1.500
SPLIT AS SHOWN
MACHINE 2.000 D (NOM.)
AT ASS'Y OF BOTH COMPONENTS
OF THIS PART
ASSURE .0005 MIN - .001 MAX
WITH PART No.
OF THIS SUB-ASS'Y
SCRAPE THIS SURFACE
IF NECESSARY
TO ASSURE
PROPER ALIGNMENT
3/8 D. (NOM.) DRILL THRU
REAM THRU FOR PRESS FIT
WITH PART No 4
OF THIS SUB ASS'Y
2 HOLES
8
MAT'L ~ BERYLLIUM COPPER
(MAY BE BRASS)
1 REQ'D
SCALE ~ 2/1
SNUG FIT
WITH PART No. 7
OF THIS SUB-ASS'Y
.025 × .025 DEEP
CUT GROOVE
FOR SCREWDRIVER
.125 D. (NOM.)
.340
.140
#4-40UNC-2A
CLEAN END OF THD
AS INDICATED
7
MAT'L ~ SEE BELOW
1 REQ'D
SCALE ~ 1/1
SNUG FIT
WITH PART No. 1
OF SUB-ASS'Y
"LAUNCH COIL"
1/8 D (NOM.) DRILL THRU
REAM THRU FOR SNUG FIT
WITH PART No. 8 OF THIS SUB ASS'Y
LOCATE AT ASS'Y WITH PART No. 10
OF SUB ASS'Y "PICK UP COIL DRIVE"
10.050
9.500 REF.
.550
.250 (NOM.)
2.125 D
1.750 D (NOM.)
2.000 D
DIA "A"
.235
DIA "A" : 1.4988 ... COPPER
LIST OF PARTS
* STOCK ITEMS
8 SCREW MAT'L ~ BERYLLIUM COPPER OR BRASS 1
7 WAVEGUIDE MAT'L ~ COPPER OR BRASS 1
6 SUPPORT WITH COVER MAT'L ~ 6061 ALUMINUM 1
*5 BRASS SCREW #6 32UNC FIL. HEAD 2
*4 ... PIN ... .1250 D ... DRILL ROD 2
*3 BRASS SCREW #8 32UNC FILLISTER HEAD, LONG 4
2 NUT MAT'L ~ BRASS 1
1 MODE FILTER MAT'L ~ BRASS & BAKELITE 1
PIECE NO.
NOMENCLATURE
NO. REQ.
ORIGINAL DATE OF DRAWING JULY 3 1967
REVISIONS
CHANGE
DATE
NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY BOULDER, COLORADO 80302
CIRCULAR WAVEGUIDE
BELOW CUT OFF ATTENUATOR
NOMINAL 30 MHz
MODEL
TYPE
SCALE
DRAFTSMAN
A. L. SCHUSTER
PROJECT
CHIEF DRF
CHIEF ENGINEER
APPROVED BY
THIS PRINT ISSUED
AI - 7/153 D
SHEET 10 OF 13
PRECISION WAVEGUIDE (SHEET #10)

Figure 27(k).

ORIGINAL DATE OF DRAWING July 31 1967

REVISIONS

NO	E C N	CHANGE	DATE
1			
2			
3			
4			



LIST OF PARTS

* STOCK ITEMS

PIECE NO	NOMENCLATURE	NO REQ'D
11	COVER, TRANSPARENT SECTION MAT'L ~ LUCITE 1/8 THICK	1
10	SPACER MAT'L ~ FELT 1/16 THICK	1
9	COVER, MAT'L ~ 52 S ALUMINUM .081 THICK	1
8	ESCUTCHEON MAT'L ~ 6061 ALUMINUM 1/16 THICK	1
*7	BRASS SCREW, #4 40 UNC, BINDING HEAD, 3/8 LONG	2
*6	BRASS SCREW, #2 - 56 UNC ROUND HEAD 3/16 LONG	6
5	INDICATOR PLATE MAT'L ~ 6061 ALUMINUM	1
*4	DIRECTIONAL SWITCH 2 SWITCHES SWITCHCRAFT # 3006 SW	1
*3	PLUG, 2 POLE INSERT W/GROUND 125 V , 15 AMP	1
*2	LITTELFUSE 3AG, 3/16 A FUSE W/FUSE MOUNT TYPE 342001	1
*1	BRASS SCREW, #6 - 32 UNC BINDING HEAD, 1/4 LONG	2

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RADIO STANDARDS LABORATORY, BOULDER, COLORADO, 80302

CIRCULAR WAVEGUIDE
BELOW CUT OFF ATTENUATOR

FOR NOMINAL 30 MHz OPERATION

MODEL VII	TYPE	SCALE AS NOTED
DIMENSIONS IN INCHES (Unless otherwise specified) TOLERANCES (Unless otherwise specified) DECIMALS ±.000 FRACTIONS ±.010 ANGLES ±½°	DRAFTSMAN Victor Lecinski	A.L. SCHUSTER
	PROJECT ENGR D.H. RUSSELL	PROJECT ENGR
	SUBMITTED BY	CHIEF SEC
DO NOT SCALE THIS PRINT	EXAMINED BY	CHIEF ENGINEER
DIV. SEC. 252/21	THIS PRINT ISSUED	APPROVED BY CHIEF DIV
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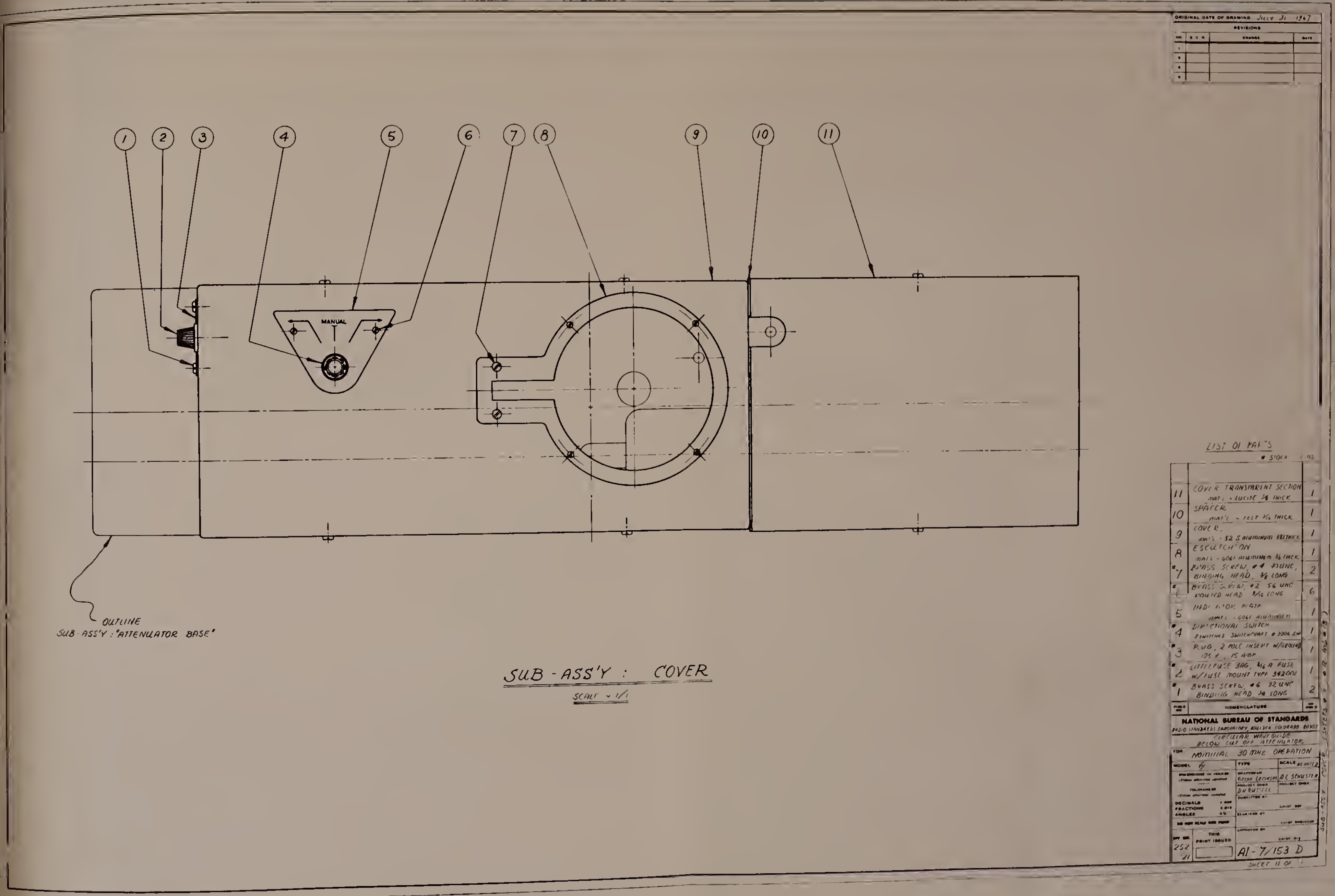
SHEET 11 OF 13

SUB-ASS'Y : COVER (SHEETS # 11 , # 12 AND # 13)

Figure 27(1).



LIST OF PARTS

\# STOCK ITEMS

11	COVER TRANSPARENT SECTION MAT'L - LUCITE 1/4 THICK	1
10	SPACER MAT'L - FELT 1/16 THICK	1
9	COVER, MAT'L - 52 S ALUMINUM 1/8 THICK	1
8	ESCUTCHEON MAT'L - 6061 ALUMINUM 1/8 THICK	1
*7	BRASS SCREW, # 4 40UNC, BINDING HEAD, 1/4 LONG	2
*6	BRASS SCREW, #2 56 UNC ROUND HEAD 3/16 LONG	6
5	INDICATOR PLATE MAT'L - 6061 ALUMINUM	1
*4	DIRECTIONAL SWITCH 2 POSITIONS SWITCHCRAFT # 3006 SW	1
*3	PLUG, 2 POLE INSERT W/GROUND 125 V, 15 AMP	1
*2	LITTELFUSE 3AG, 1/16 A FUSE W/FUSE MOUNT TYPE 342001	1
*1	BRASS SCREW, #6 32 UNC BINDING HEAD, 3/8 LONG	2
PIECE NO.	NOMENCLATURE	NO. REQ'D

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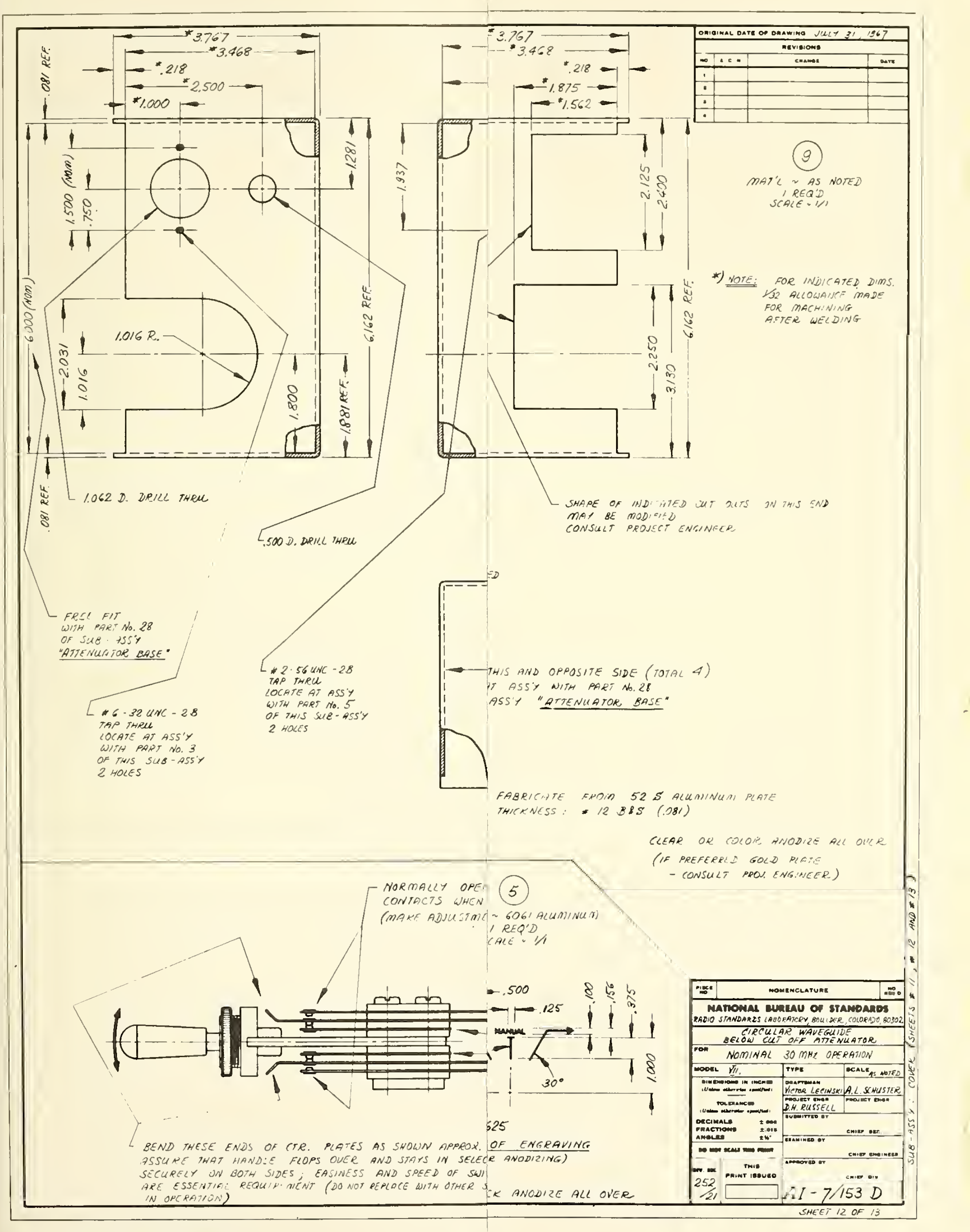
RADIO STANDARDS LABORATORY, BOULDER, COLORADO 80302

CIRCULAR WAVEGUIDE
BELOW CUT OFF ATTENUATOR,

FOR NOMINAL 30 MHz OPERATION

MODEL
TYPE
SCALE AS NOTED
DIMENSIONS IN INCHES (Unless otherwise specified)
TOLERANCES (Unless otherwise specified)
DECIMALS
FRACTIONS
ANGLES
DO NOT SCALE THIS PRINT
DRAFTED BY Victor Lecinski
A L SCHUSTER
PROJECT ENGR. D H RUSSELL
PROJECT ENGR.
SUBMITTED BY
CHIEF OF
EXAMINED BY
CHIEF ENGINEER
APPROVED BY
CHIEF OF
OFF. DIV. 252 .41
THIS PRINT ISSUED
AI - 7/153 D
SHEET 11 OF

Figure 27(1).


ORIGINAL DATE OF DRAWING JULY 31, 1967
REVISIONS
NO
E C N
CHANGE
DATE
9
MAT'L ~ AS NOTED
1 REQ'D
SCALE ~ 1/1
*3.767
*3.468
*.218
*2.500
*1.000
.081 REF.
1.500 (NOM)
.750
1.281
6.000 (NOM)
2.031
1.016
1.016 R.
6.162 REF.
1.800
1.881 REF.
.081 REF.
1.062 D. DRILL THRU
.500 D. DRILL THRU
*1.875
*1.562
1.937
2.125
2.400
2.250
3.130
*) NOTE: FOR INDICATED DIMS. 1/32 ALLOWANCE MADE FOR MACHINING AFTER WELDING
SHAPE OF INDICATED CUT OUTS ON THIS END MAY BE MODIFIED
CONSULT PROJECT ENGINEER
FREE FIT WITH PART No. 28 OF SUB - ASS'Y "ATTENUATOR BASE"
6 - 32 UNC - 28 TAP THRU LOCATE AT ASS'Y WITH PART No. 3 OF THIS SUB - ASS'Y 2 HOLES
2 - 56 UNC - 28 TAP THRU LOCATE AT ASS'Y WITH PART No. 5 OF THIS SUB - ASS'Y 2 HOLES
ED
THIS AND OPPOSITE SIDE (TOTAL 4)
T ASS'Y WITH PART No. 28
ASS'Y "ATTENUATOR BASE"
FABRICATE FROM 52 S ALUMINUM PLATE
THICKNESS : # 12 B&S (.081)
CLEAR OR COLOR ANODIZE ALL OVER
(IF PREFERRED GOLD PLATE - CONSULT PROJ. ENGINEER)
5
NORMALLY OPE
CONTACTS WHEN
(MAKE ADJUSTME
~ 6061 ALUMINUM)
1 REQ'D
CALE ~ 1/1
.500
.125
.100
.156
.375
MANUAL
30°
1.000
625
BEND THESE ENDS OF CTR. PLATES AS SHOWN APPROX.
ASSURE THAT HANDLE FLOPS OVER AND STAYS IN SELEC
SECURELY ON BOTH SIDES ; EASINESS AND SPEED OF SWI
ARE ESSENTIAL REQUIREMENT (DO NOT REPLACE WITH OTHER S
IN OPERATION)
OF ENGRAVING
R ANODIZING)
CK ANODIZE ALL OVER
PIECE NO
NOMENCLATURE
NO REQ'D
NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER, COLORADO, 80302
CIRCULAR WAVEGUIDE BELOW CUT OFF ATTENUATOR
FOR NOMINAL 30 MHz OPERATION
MODEL VII.
TYPE
SCALE AS NOTED
DIMENSIONS IN INCHES (Unless otherwise specified)
TOLERANCES (Unless otherwise specified)
DECIMALS ±.005
FRACTIONS ±.015
ANGLES ±½°
DO NOT SCALE THIS PRINT
DRAFTSMAN
VICTOR LECINSKI
A.L. SCHUSTER
PROJECT ENGR
D.H. RUSSELL
PROJECT ENGR
SUBMITTED BY
CHIEF SEC.
EXAMINED BY
CHIEF ENGINEER
APPROVED BY
CHIEF DIV
DRW. BK
252/21
THIS PRINT ISSUED
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SHEET 12 OF 13
SUB - ASS'Y : COVER (SHEETS # 11, # 12 AND # 13)

Figure 27(m).

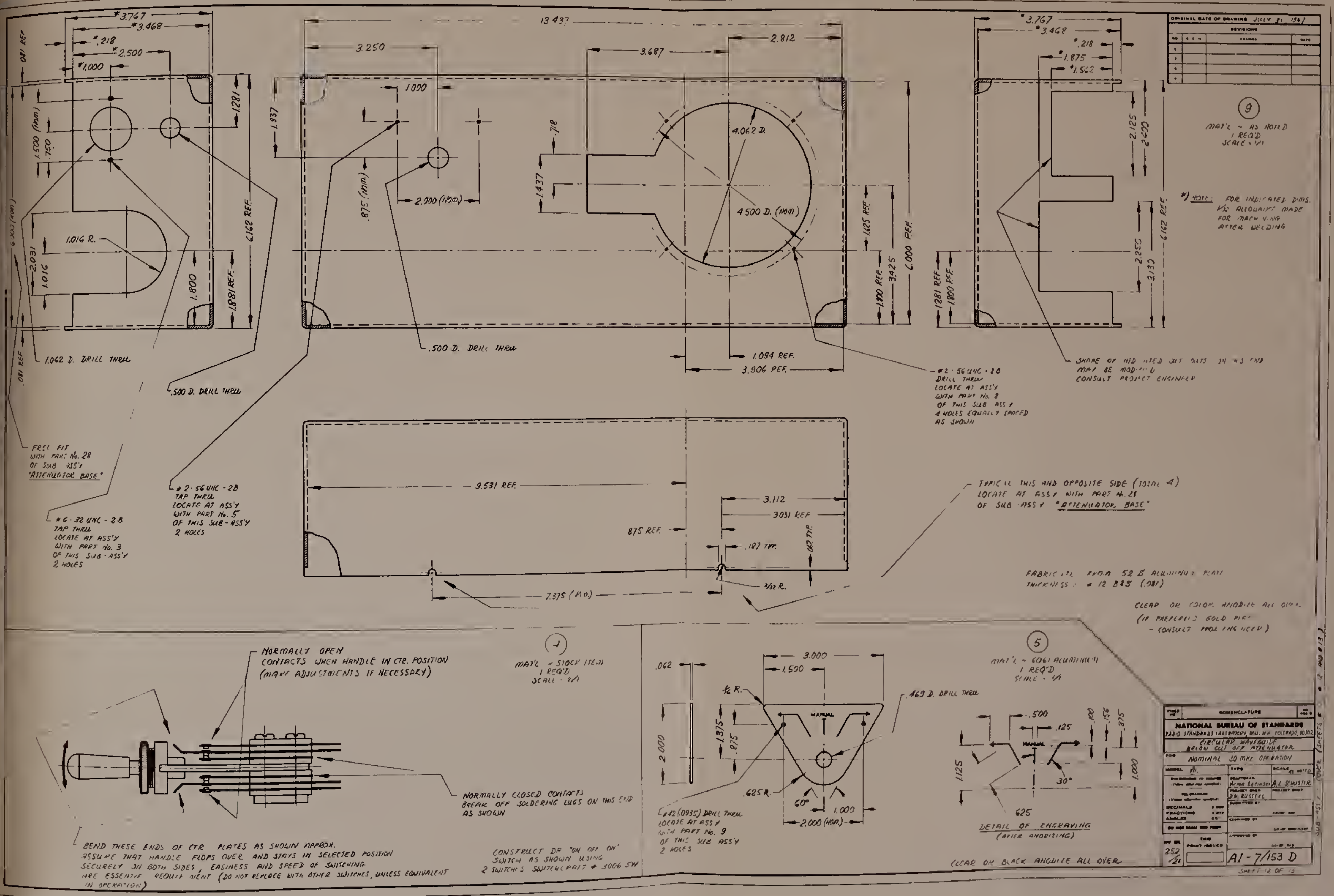
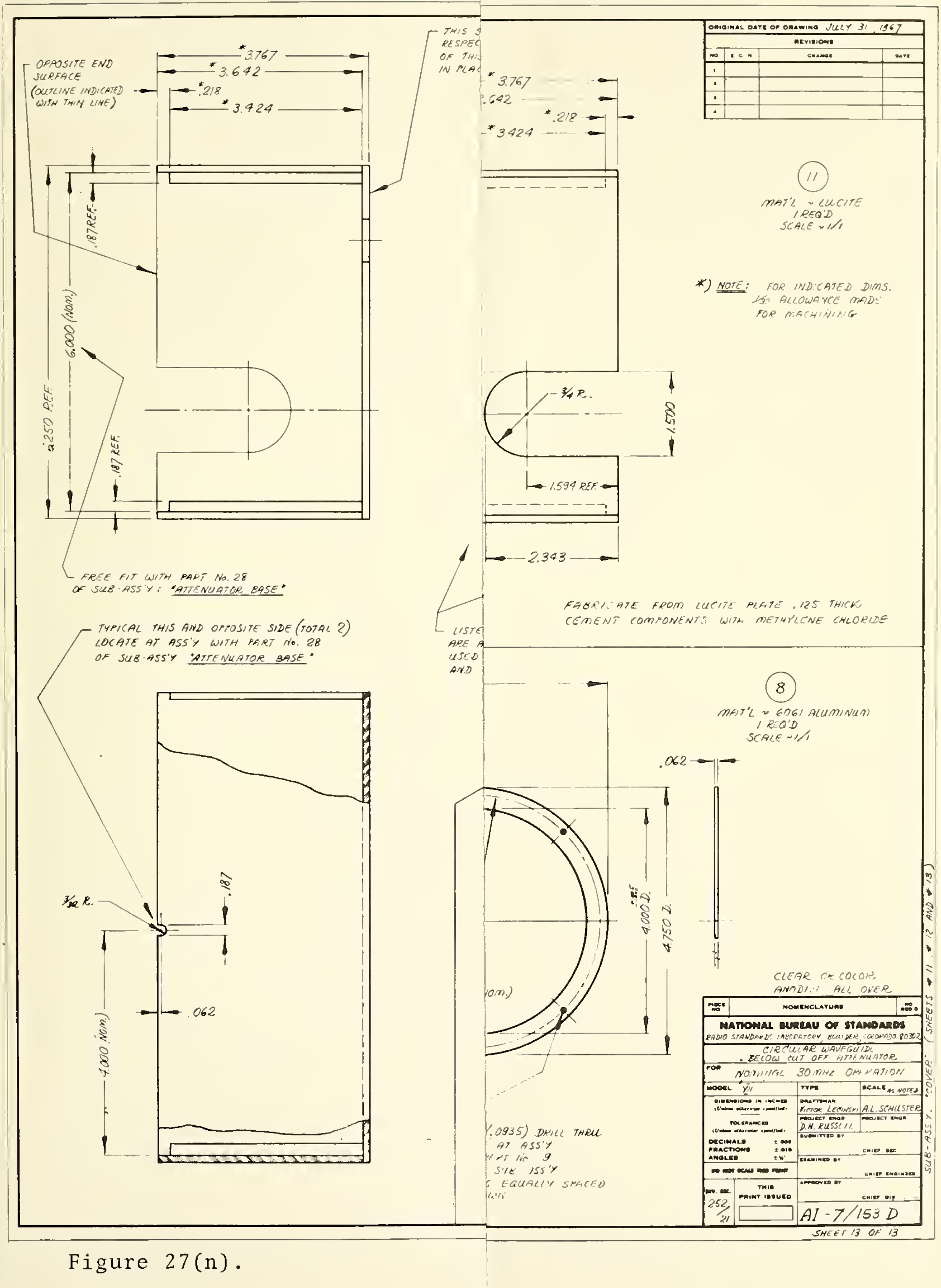

ORIGINAL DATE OF DRAWING JULY 31, 1967
REVISIONS
9
MAT'L ~ AS NOTED
1 REQ'D
SCALE - 1/1
*) NOTE: FOR INDICATED DIMS. 1/32 ALLOWANCE MADE FOR MACHINING AFTER WELDING
*3.767
*3.468
*.218
*2.500
*1.000
1.062 D. DRILL THRU
.500 D. DRILL THRU
FREE FIT WITH PART No. 28 OF SUB ASS'Y "ATTENUATOR BASE"
6 - 32 UNC - 2B TAP THRU LOCATE AT ASS'Y WITH PART No. 3 OF THIS SUB - ASS'Y 2 HOLES
2 - 56 UNC - 2B TAP THRU LOCATE AT ASS'Y WITH PART No. 5 OF THIS SUB - ASS'Y 2 HOLES
13.437
3.250
3.687
2.812
1.000
.500 D. DRILL THRU
2.000 (Nom.)
.875 (Min.)
4.062 D.
4.500 D. (Nom)
1.094 REF.
3.906 REF.
6.000 REF.
#2 - 56 UNC - 2B DRILL THRU LOCATE AT ASS'Y WITH PART No. 8 OF THIS SUB ASS'Y 4 HOLES EQUALLY SPACED AS SHOWN
*1.875
*1.562
2.125
2.250
6.162 REF.
SHAPE OF INDICATED CUT OUTS IN AS END MAY BE MODIFIED CONSULT PROJECT ENGINEER
9.531 REF.
3.112
3.031 REF
.875 REF.
.187 TYP.
7.375 (Min.)
1/32 R.
TYPICAL THIS AND OPPOSITE SIDE (TOTAL 4) LOCATE AT ASS'Y WITH PART No. 21 OF SUB - ASS'Y "ATTENUATOR BASE"
FABRICATE FROM 52 S ALUMINUM PLATE THICKNESS: # 12 B&S (.081)
CLEAR OR COLOR ANODIZE ALL OVER (IF PREFERRED GOLD FIN. - CONSULT PROJ. ENGINEER)
NORMALLY OPEN CONTACTS WHEN HANDLE IN CTR. POSITION (MAKE ADJUSTMENTS IF NECESSARY)
NORMALLY CLOSED CONTACTS BREAK OFF SOLDERING LUGS ON THIS END AS SHOWN
BEND THESE ENDS OF CTR PLATES AS SHOWN APPROX. ASSURE THAT HANDLE FLOPS OVER AND STAYS IN SELECTED POSITION SECURELY ON BOTH SIDES, EASINESS AND SPEED OF SWITCHING ARE ESSENTIAL REQUIREMENT (DO NOT REPLACE WITH OTHER SWITCHES, UNLESS EQUIVALENT IN OPERATION)
4
MAT'L - STOCK ITEM
1 REQ'D
SCALE - 2/1
CONSTRUCT "ON OFF ON" SWITCH AS SHOWN USING 2 SWITCHES SWITCHCRAFT # 3006 SW
.062
3.000
1.500
1/2 R.
.469 D. DRILL THRU
MANUAL
2.000
1.375
.875
.625 R.
60°
1.000
2.000 (Nom.)
#42 (.0935) DRILL THRU LOCATE AT ASS'Y WITH PART No. 9 OF THIS SUB ASS'Y 2 HOLES
5
MAT'L - 6061 ALUMINUM
1 REQ'D
SCALE - 1/1
.500
.125
30°
.625
1.125
1.000
DETAIL OF ENGRAVING (AFTER ANODIZING)
CLEAR OR BLACK ANODIZE ALL OVER
NOMENCLATURE
NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER, COLORADO, 80302
CIRCULAR WAVEGUIDE BELOW CUT OFF ATTENUATOR
NOMINAL 30 MHz OPERATION
DRAFTSMAN Mena Lepinski A.L. SCHUSTER
PROJECT ENGR D.H. RUSSELL
252/21
AI - 7/153 D
SHEET 12 OF 15

Figure 27(m).


ORIGINAL DATE OF DRAWING JULY 31, 1967
REVISIONS
NO
E C N
CHANGE
DATE
1
2
3
4
OPPOSITE END SURFACE (OUTLINE INDICATED WITH THIN LINE)
*3.767
*3.642
*.218
*3.424
THIS S
RESPEC
OF THI
IN PLAC
*3.767
3.642
*.218
*3424
.187 REF.
6.000 (Nom.)
6.250 REF.
.187 REF.
¾ R.
1.500
1.594 REF.
2.343
11
MAT'L ~ LUCITE
1 REQ'D
SCALE ~ 1/1
*) NOTE: FOR INDICATED DIMS. 1/32 ALLOWANCE MADE FOR MACHINING
FREE FIT WITH PART No. 28 OF SUB-ASS'Y: "ATTENUATOR BASE"
FABRICATE FROM LUCITE PLATE .125 THICK CEMENT COMPONENTS WITH METHYLENE CHLORIDE
LISTE
ARE A
USED
AND
TYPICAL THIS AND OPPOSITE SIDE (TOTAL 2) LOCATE AT ASS'Y WITH PART No. 28 OF SUB-ASS'Y "ATTENUATOR BASE"
8
MAT'L ~ 6061 ALUMINUM
1 REQ'D
SCALE ~ 1/1
.062
3/32 R.
.187
.062
4.000 (Nom.)
(Nom.)
4.000 D.
4.750 D.
(.0935) DRILL THRU
AT ASS'Y
PART No. 9
SUB-ASS'Y
EQUALLY SPACED
CLEAR OR COLOR ANODIZE ALL OVER
PIECE NO
NOMENCLATURE
NO REQ'D
NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER, COLORADO 80302
CIRCULAR WAVEGUIDE BELOW CUT OFF ATTENUATOR
FOR NOMINAL 30 MHz OPERATION
MODEL VII
TYPE
SCALE AS NOTED
DIMENSIONS IN INCHES (Unless otherwise specified)
TOLERANCES (Unless otherwise specified)
DECIMALS ± .005
FRACTIONS ± .010
ANGLES ± ½°
DO NOT SCALE THIS PRINT
DRAFTSMAN Victor Lecinski
A.L. SCHULSTER
PROJECT ENGR D.H. RUSSELL
PROJECT ENGR
SUBMITTED BY
CHIEF SEC.
EXAMINED BY
CHIEF ENGINEER
APPROVED BY
CHIEF DIV.
DIV. SEC. 252/21
THIS PRINT ISSUED
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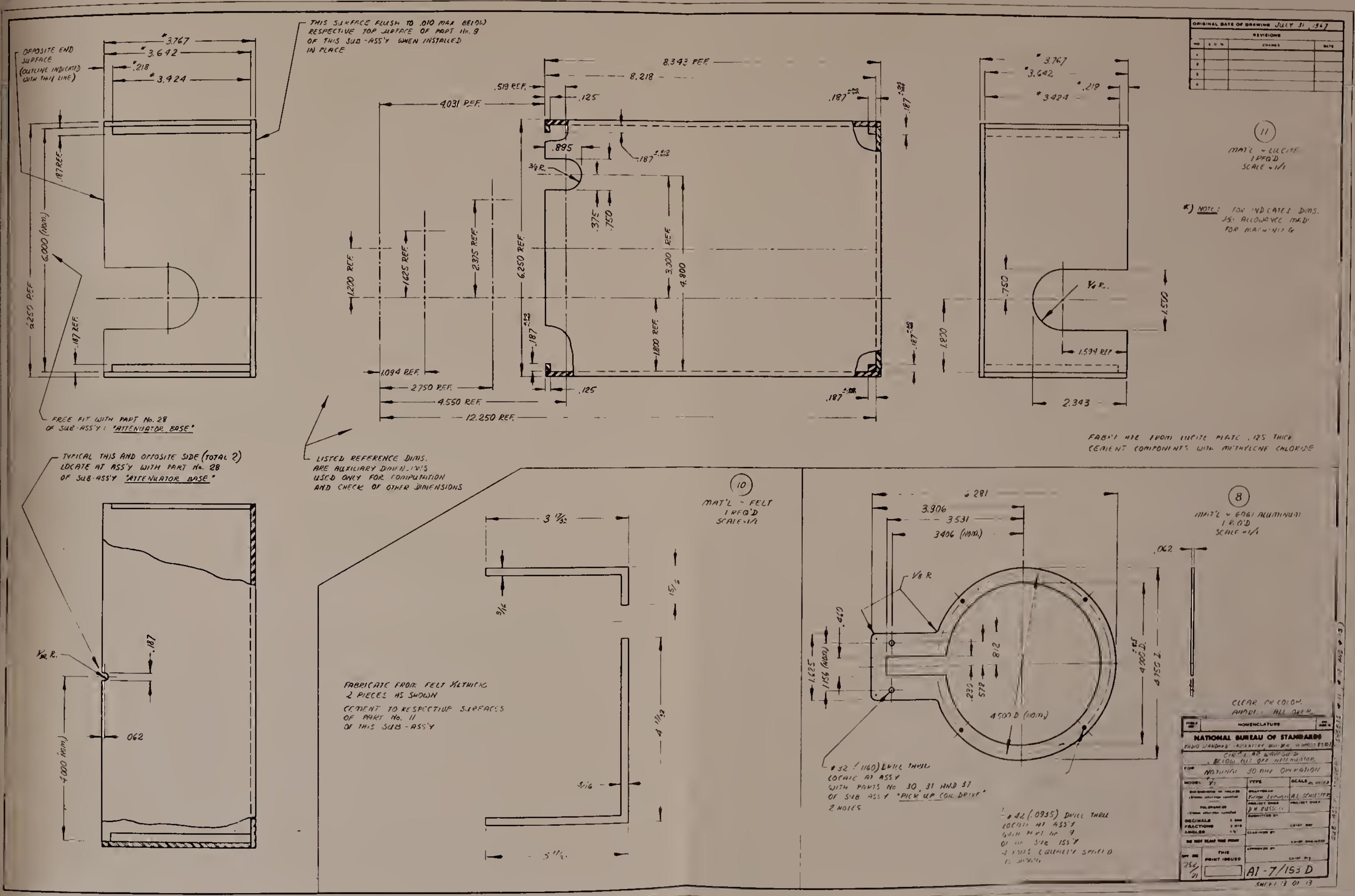
SHEET 13 OF 13
SUB-ASS'Y. "COVER" (SHEETS #11, #12 AND #13)

Figure 27(n).

OPPOSITE END SURFACE (OUTLINE INDICATED WITH THIS LINE)
*3.767
*3.642
*.218
*3.424
THIS SURFACE FLUSH TO .010 MAX BELOW RESPECTIVE TOP SURFACE OF PART No. 9 OF THIS SUB-ASS'Y WHEN INSTALLED IN PLACE
.187 REF.
6.000 (NOM.)
3.250 REF.
.187 REF.
FREE FIT WITH PART No. 28 OF SUB-ASS'Y: "ATTENUATOR BASE"
8.343 REF.
8.218
.519 REF.
.125
4.031 REF.
.895
3/8 R.
.187
.375
.750
3.200 REF.
4.800
1.800 REF.
1.200 REF.
1.625 REF.
2.375 REF.
6.250 REF.
1.094 REF.
2.750 REF.
4.550 REF.
12.250 REF.
LISTED REFERENCE DIMS. ARE AUXILIARY DIMENSIONS USED ONLY FOR COMPUTATION AND CHECK OF OTHER DIMENSIONS
*.219
1/4 R.
.750
1.570
1.820
1.594 REF.
2.343
11
MAT'L ~ LUCITE 1 REQ'D SCALE = 1/1
*) NOTE: FOR INDICATED DIMS. 1/16 ALLOWANCE MADE FOR MACHINING
FAB'T ARE FROM LUCITE PLATE .125 THICK CEMENT COMPONENTS WITH METHYLENE CHLORIDE
TYPICAL THIS AND OPPOSITE SIDE (TOTAL 2) LOCATE AT ASS'Y WITH PART No. 28 OF SUB-ASS'Y "ATTENUATOR BASE"
1/32 R.
.187
.062
4.000 (NOM.)
10
MAT'L ~ FELT 1 REQ'D SCALE = 1/1
3 17/32
9/16
15/16
4 11/32
5/16
5 11/32
FABRICATE FROM FELT 1/16 THICK 2 PIECES AS SHOWN
CEMENT TO RESPECTIVE SURFACES OF PART No. 11 OF THIS SUB-ASS'Y
4.281
3.906
3.531
3.406 (NOM.)
1/8 R
.460
1.625
1.156 (NOM.)
.812
.230
.578
4.500 D (NOM.)
4.000 D.
4.750 D.
.062
8
MAT'L ~ 6061 ALUMINUM 1 REQ'D SCALE = 1/1
CLEAR OR COLOR ANODIZE ALL OVER
32 (.1160) DRILL THRU LOCATE AT ASS'Y WITH PARTS No 30, 31 AND 37 OF SUB ASS'Y "PICK UP COIL DRIVE" 2 HOLES
42 (.0935) DRILL THRU LOCATE AT ASS'Y WITH PART No 9 OF THIS SUB ASS'Y 4 HOLES EQUALLY SPACED AS SHOWN
ORIGINAL DATE OF DRAWING JULY 31, 1967
REVISIONS
NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY BOULDER, COLORADO 80302
CIRCULAR WAVEGUIDE BELOW CUT OFF ATTENUATOR
FOR NATIONAL 30 MHZ OPERATION
SCALE AS NOTED
VICTOR LEAGUE
AL SCHUSTER
D.H. RUSSELL
DECIMALS
FRACTIONS
ANGLES
DO NOT SCALE THIS PRINT
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SUB-ASS'Y "ATTENUATOR BASE" SHEETS # 11, # 12 AND # 13

Figure 27(n).

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16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

This paper presents the details to implement a WR 15 attenuation and reflection coefficient magnitude measurement system. A discussion of precision and of systematic error is given along with equations for estimating limits of the error. Machine drawings are provided to fabricate the waveguide standards and necessary hardware not commercially available.

17. KEY WORDS (Alphabetical order, separated by semicolons)

Attenuation; Measurement system; Millimeter; Reflection coefficient, VSWR.

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