



The NOTEBOOK

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Applications of a Sweep Signal Generator

FRANK G. MARBLE, Vice President - Sales

The design techniques used in the development of a new Sweep Frequency Signal Generator were discussed in the Spring 1955 Number 5 Issue of THE NOTEBOOK.* That discussion covered the methods used to obtain the performance required of a precision AM modulated Signal Generator, sweep and marker system in a single instrument. This article continues the discussion by considering some of the various methods by which such an instrument can be used.

One advantage of a sweep frequency signal generator lies in its ability to save time and thus economize engineering manpower, freeing it for other constructive work. One might, for instance, use an adjustable frequency, adjustable level cw signal generator to obtain output-vs-input data for an if amplifier at several discrete frequency points. This data can then be plotted on a graph showing response-vs-frequency to obtain the pass-band of the circuit. For each circuit readjustment this procedure must be repeated. For a narrow pass-band circuit this process is at best tedious, but for a broad-band circuit its time requirements are virtually prohibitive.

The simultaneous display of the response-vs-frequency curve of a circuit on the screen of a cathode ray oscilloscope by a sweep frequency signal generator system and the instantaneous indication of changes caused by adjustments expedites the engineer's work enormously. Another advantage of the sweep method is the practical fact that some of the time so saved will be used to obtain refinements which would have been overlooked using the slower single frequency methods.

*"Sweep Frequency Signal Generator Design Techniques" John H. Mennie and Chi Lung Kang - The Notebook Spring 1955 Number 5.

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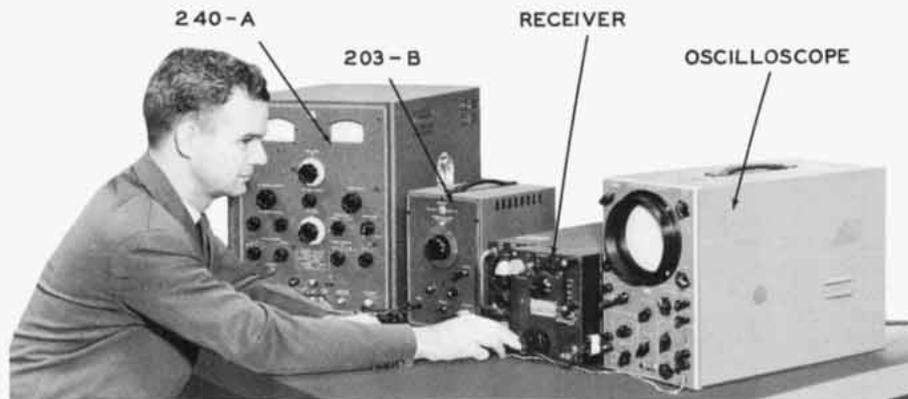


Figure 1. The author adjusts the pass-band of the IF amplifier below the 4.5 mc lower limit of the Sweep Signal Generator 240-A by using the Univerter Type 203-B. This combination permits cw and sweep measurements from 0.1 to 120 megacycles per second.

Besides the savings in time and the greater practical refinement obtained, some information is immediately observed by sweep methods which can be easily overlooked in the point by point method. Regeneration effects and "suck-outs" may cause changes in the response curve which persist over only a very narrow range of frequencies. Since cw measurements are made at discrete frequency points only, it is possible to obtain a smooth response curve excluding these effects if they happen to lie between the selected measurement points. A Sweep Signal Generator presents data which is continuous with frequency. This removes the possibility of missing important information.

The Basic Measuring System

Fig 2 shows the 240-A, a broad band detector, and an oscilloscope interconnected. The resultant information which appears on the screen of the oscilloscope is shown in enlarged form in the photograph in Figure 3. The display is a graph with abscissa proportional to frequency and ordinate proportional to the amplitude response of the detector circuit.

The interconnections in Figure 2 required to obtain the display include the connection of the rf output of the signal generator to the detector whose output connects to a

marker adder circuit "Test In" in the Signal Generator and hence to the vertical deflection amplifier of the oscilloscope. The sawtooth of

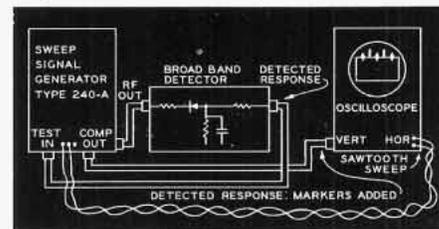


Figure 2. Typical interconnections of Sweep Signal Generator Type 240-A, Test Circuit (Broad Band Detector) and Oscilloscope.

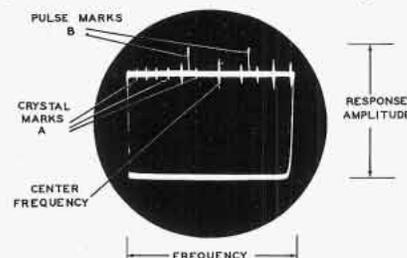


Figure 3. Enlarged photograph of the display appearing on the screen of the oscilloscope in figure 2.

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voltage which frequency modulates the constant-amplitude RF output of the Signal Generator is connected to the horizontal deflection amplifier of the oscilloscope.

The sawtooth voltage, while increasing in amplitude, modulates the constant amplitude RF output from a minimum to a maximum frequency. Simultaneously it deflects the oscilloscope from left to right. At the maximum frequency point the sawtooth starts decreasing in amplitude, the rf output of the signal generator is reduced to zero, the oscilloscope deflected from right to left and the tuning mechanism of the signal generator returned to the minimum frequency point. The constant amplitude rf output reappears and the cycle is repeated.

The lower line in the display in Figure 3 represents the reference line of the graph or line of zero input and the upper line the detector response curve.

The frequencies along the Abscissa must be identified if the response curve is to have meaning. In the Sweep Signal Generator Type 240-A, frequency identification is accomplished by two types of marks. The marks at (a) in Figure 3 appear at the harmonics of a crystal oscillating at 2.5, 0.5, or 0.1 megacycles. The marks indicated by the arrows marked (A) have separation of 2.5 megacycles. The center frequency can be identified from the tuning dial of the Signal Generator. With the center frequency identified the frequency of each of the other marks can be deduced since the frequency spacing is known.

The marks at (B) on Figure 3 are sharp narrow pulses. The position of these pulses can be adjusted along the frequency axis by

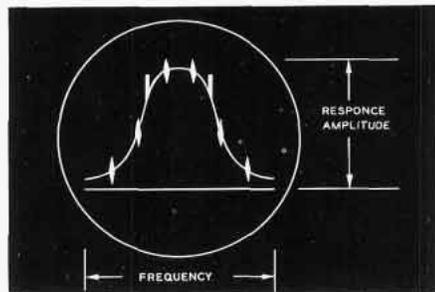


Figure 4. Oscilloscope display resulting from insertion of a selective circuit and associated detector in Sweep Signal Generator test circuit.

front panel controls. The crystal marks can be switched off after the pulses have been positioned to coincide with any two of these marks. This leaves these two frequencies marked in a manner which causes minimum interference with the reference curve. The pulses (B) can also be positioned between two crystal marks (A) since the frequency changes linearly with distance. The crystal marks can then be switched off. In this way, any two frequencies along the frequency axis can be marked.

The marks shown at (A) and (B) on Figure 3 are added to the display in the marker-adder circuit through which the signal from the detector (shown in Figure 2) passes before it is connected to the vertical deflection amplifier of the oscilloscope.

Determination of Selectivity and Sensitivity

The elements of a Sweep Signal Generator system for measuring selectivity and sensitivity of a test circuit are the same as shown in Figure 2 with the test circuit inserted between the RF output and the detector. If the test circuit contains a detector, the detector in Figure 2 can obviously be omitted. The resultant display appears in Figure 4. The constant amplitude signal source is frequency modulated or swept from a low to a higher frequency at a slow rate compared to the signal frequency. When the maximum frequency of the sweep is reached the signal source output is turned off and the generator returned to the low frequency point for a subsequent sweep from low to high frequency.

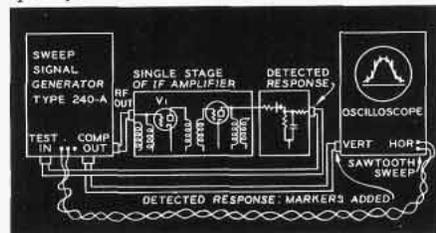


Figure 5. Interconnections for observation of pass band of a single stage within an IF amplifier.

The test circuit detector provides response curve of attenuation vs. frequency and frequency identification marks are added to the varying signal from the test circuit.

The horizontal deflection connections of the oscilloscope are connected to the same voltage that sweeps the signal source. The display on the oscilloscope, Figure 4, includes the response vs. frequency response of the test circuit, the frequency identification marks and a base or zero reference line indicating the level out of the test circuit with no input. The selectivity of the test circuit is apparent from a comparison of the change in response vs. the number of megacycles or kilocycles per inch along the horizontal axis of the display. This frequency calibration of the horizontal axis is deduced from the markers shown.

Selectivity usually varies with signal level as a result of AGC, limiters, non-linear

amplifier, etc. Therefore it is important to test it at various operating signal levels. The Sweep Signal Generator Type 240-A, mentioned in the article cited in the first paragraph of this article, provides calibrated output level from 1.0 to 300,000 microvolts while sweeping. Its leakage is sufficiently low to permit use of an external 20 db attenuator to obtain outputs down to 0.1 microvolt.

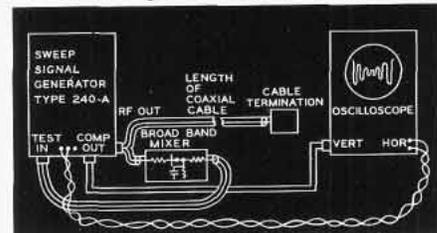


Figure 6. Interconnections for study of cable and cable termination characteristics.

Selectivity of Single Stages

The system of connection in Figure 2 is suitable for receivers, filters or amplifiers. The terminated rf cable (a 50 ohm system) is connected into the input of the test circuit. The detector of the test circuit is connected to the marker adder circuit in the sweep signal generator (input impedance 1 meg-ohm). The use of a sweep signal source is not limited to complete receivers or amplifiers, however. So long as arrangements are made to avoid any effect on the sensitivity or selectivity of the circuit under test by the impedance of the rf output of the Sweep Signal Generator or of the detector the selectivity-sensitivity characteristics of any circuit may be observed within the sensitivity limits of the oscilloscope being used.

A convenient method of observing the pass band of a single stage appears in Figure 5. The output of the Sweep Signal Generator connects to the grid of the tube which contains the test stage in its plate circuit. A broad band detector is connected to the plate of the following stage through a coupling condenser. The low input impedance of the detector lowers the Q of the circuit in the plate of this tube so materially as to make its effect on the final result insignificant. The tuned circuit of tube V1 is operating under its normal condition and its sensitivity-selectivity characteristic can be observed on the oscilloscope.

Study of Pass Band Characteristics

The Q of the pass band of a test circuit can be approximately deduced by use of a sweep signal generator. As discussed above the response curve of a circuit can be displayed on an amplitude vs. frequency graph on the face of a cathode ray tube. The marking system of the Sweep Frequency Signal Generator makes it possible to identify any frequency along the horizontal axis. Since the response in the vertical direction on the oscilloscope is linear, a point 0.707 times the distance from the zero or reference line to the peak of the response curve can be located on each side of the peak. From the frequency marking system the frequency difference

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(Δf) between these two points and the frequency of the peak can be obtained. Q can then be obtained from the following formula: $Q = \frac{f_0}{\Delta f}$

Adjustment or Stagger Tuned Circuits

Broad pass bands are often obtained by adjusting the resonant frequencies of successive single tuned circuits to slightly different frequencies within the desired pass band. The overall result is a relatively flat pass band broader in frequency than any one of the individual tuned circuits.

To adjust this type of amplifier, it is normally quicker to first resonate each individual circuit to the proper frequency with a cw signal generator. After completion of this procedure, the overall pass band configuration can be investigated and "touch up" adjustment made with a sweep signal generator. The Sweep Signal Generator Type 240-A is excellently suited to this procedure since it operates as a cw (with or without AM) or sweep signal generator, without the necessity of disturbing the input or output connections to the test circuit. A Vacuum Tube Voltmeter can be bridged across the input to the vertical deflection amplifier input of the oscilloscope for the single frequency work. The oscilloscope of course is used for the overall investigation and "touch up." Since the output monitoring and attenuation system is equally applicable to cw and sweep work the sensitivity can easily be checked under either condition.

Study of Cable Characteristics

The characteristics of high frequency cables may be investigated by use of a sweep frequency signal generator. In Figure 6 a sweep signal generator is shown connected to the input of a length of high frequency cable. Also connected to the input of the cable is a wide band detector. The low frequency sweep voltage from the sweep signal generator is connected to the horizontal deflection input of the oscilloscope. The RF signal, swept or frequency modulated at a low rate of 60 times per second, is fed into the cable. Reflected signal from imperfections in the cable or the termination arrives back at the

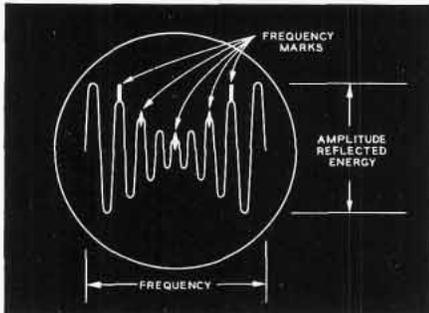


Figure 7. Oscilloscope display indicating amplitude of reflected energy from a termination coaxial cable.

input a finite time later. Since during this finite time the input signal has changed to a new frequency, an audio difference frequency (input frequency minus reflected frequency) appears across the output of the detector. The amplitude of the input signal

is great and constant and the reflected frequency amplitude for a near match is small and variable. The amount of energy reflected from the end of the line depends on the correctness of the termination and varies from zero for a perfect match to a finite value proportional to the mismatch for mismatched lines. Since the termination impedance will, in general, vary with frequency, the amount of energy reflected will also vary. The audio frequency from the detector appears on the oscilloscope. The envelope amplitude of the display is proportional to the instantaneous reflected signal and the abscissa is proportional to frequency of the RF input as shown in Figure 7.

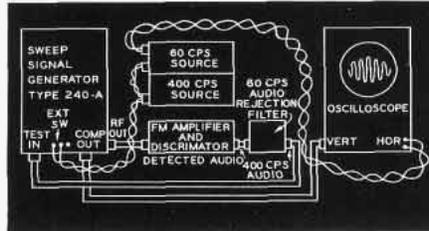


Figure 8. Diagram of equipment and connections for measurement of linearity of FM discriminator.

With a perfect termination over the frequency range in question, various cables can be observed for imperfections in construction. A periodic variation in dielectric constant of the cable insulation will exhibit itself on the oscilloscope display.

Adjustable resistance load will permit quick determination of the Z_0 for long cable lengths.

The Linearity of FM Discriminators

The Sweep Signal Generator Type 240-A provides a powerful method of determining the linearity of an FM discriminator. The method is indicated in Figure 8. A low frequency (60 cps) sweep, adjusted to sweep the full frequency range of the discriminator, and a higher frequency sweep (400 cps) is fed into the EXT sweep input of the Sweep Signal Generator. The high frequency voltage is adjusted to sweep only a small fraction of the frequency range of the discriminator. In effect the high frequency sweep explores the slope of each section of the discriminator while it is slowly moved from section to section by the low frequency sweep. The output is detected and passed through a high pass filter which passes only the resulting 400 cps note. The display of the amplitude of this note vs. the low frequency sweep affords a visual display in which the slope of the amplitude of the envelope of the 400 cps note is proportional to FM discriminator linearity. A constant amplitude indicates a linear discriminator whereas a varying amplitude indicates a variation in linearity.

The Study of Crystal Modes

The rapid location of the several frequency modes at which a crystal oscillates is important but tedious by discrete frequency methods. The Sweep Signal Generator Type 240-A provides a frequency sweep on which individual frequencies can be identified by the

marker system included in the generator. A crystal, however, has such a high Q that sweep rates must be very low to prevent ringing and spurious responses. By using an oscilloscope with low frequency sawtooth sweep available, the 240-A can be swept at frequencies of 1 or 2 cps by connecting the oscilloscope sweep output to the "External

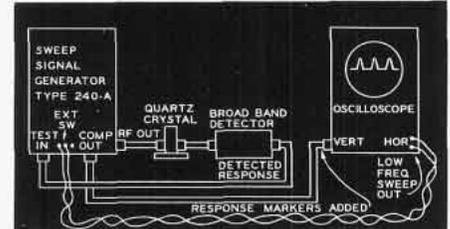


Figure 9. Equipment arrangement for measurement of quartz crystal characteristics.

Sweep" of the 240-A. The system is then connected as shown in Figure 9. By varying the center frequency of the 240-A and its sweep width the crystal can be explored for responses over a considerable frequency range.

Extension of the Frequency Range

The lowest center frequency of the Sweep Frequency Signal Generator Type 240-A is 4.5 megacycles. At this frequency the sweep frequency capabilities of the instrument are $\pm 1\%$ to $\pm 30\%$ of center frequency or ± 45 KC to ± 1.35 MC. For applications in television video amplifiers both for color and black and white, and aircraft navigation receiver intermediate frequency amplifiers, lower center frequencies and/or broader sweeps are required. Both these requirements can be met by use of the Univerter Type 203-B with the Sweep Frequency Signal Generator Type 240-A. The 203-B consists of a broad band mixer with local oscillator at 70 MC, followed by a broad band amplifier with a 50 ohm output. The gain of the 203-B is set at unity. Figure 1 shows the 240-A, 203-B in a measuring set-up. In use the 240-A is tuned to a frequency equal to 70 MC plus the desired output center frequency from the system. Sweeps from ± 0.7 MC to ± 15 MC are available. Single frequency outputs unmodulated or with AM modulation can be obtained. Thus single frequency or sweep outputs are made available over the band width of the 203-B which is 0.1 to 25 MC.

Summary

The Sweep Signal Generator is a powerful tool of considerable flexibility. It not only saves considerable time but makes refinements possible in circuit adjustment and development which would not normally be possible.

THE AUTHOR

Frank G. Marble's career covers a broad field of engineering experience: design & development work for Philco; coordinator on various government projects; two years with Western Electric's electrical research division & engineering administrative posts with Pratt & Whitney Aircraft & Kay Electrical Co. Mr. Marble has been with Boonton Radio since 1951 & a Vice-president-sales since 1954. Mr. Marble has a BS in EE (Mississippi State College 1934) & an MS in EE (M.I.T. 1935).

Use of the RF Voltage Standard Type 245-A

W. C. MOORE, *Engineering Manager*

When discrepancies exist among measurements made with different signal generators on the same radio receiver, it is often very difficult to determine just which of the instruments is performing correctly. The introduction of a reference standard usually will resolve the dilemma so that effort can profitably be applied to the offending units. However, care must be exercised in the use of such a standard and understanding applied to the interpretation of the results. This article discusses the use of a source of standardized voltage at a known impedance.

The R.F. Voltage Standard Type 245-A, shown in Figure 1, is designed to deliver, across the BNC output jack at the end of its Output Cable, open-circuit radio frequency voltages of 1/2, 1, and 2 microvolts through a source impedance of 50 ohms over the frequency range of 0.1 mc to 500 mc. It can be used in conjunction with a signal generator as a source of known voltage and impedance for determining receiver sensitivity performance. Using this source of voltage as a point of reference, it is also possible to perform relative comparisons with other sources of radio frequency voltage whose frequencies lie within the specified range. In addition, the input system is calibrated for use as a 50 ohm rf voltmeter at 0.05 volts over a wide frequency range.

Principle of Operation

A description of the RF Voltage Standard is given in the Spring, 1955 issue of the BRC Notebook¹. The system block diagram of the RF Voltage Standard is shown in Figure 2. An external source is used to supply rf voltage to the Input Cable. The voltage at the output end of this cable is indicated by an RF Voltmeter at the point where the cable is terminated by the input to the Coaxial Attenuator². The low voltage output of the Coaxial Attenuator appears in series with an impedance matching resistor.

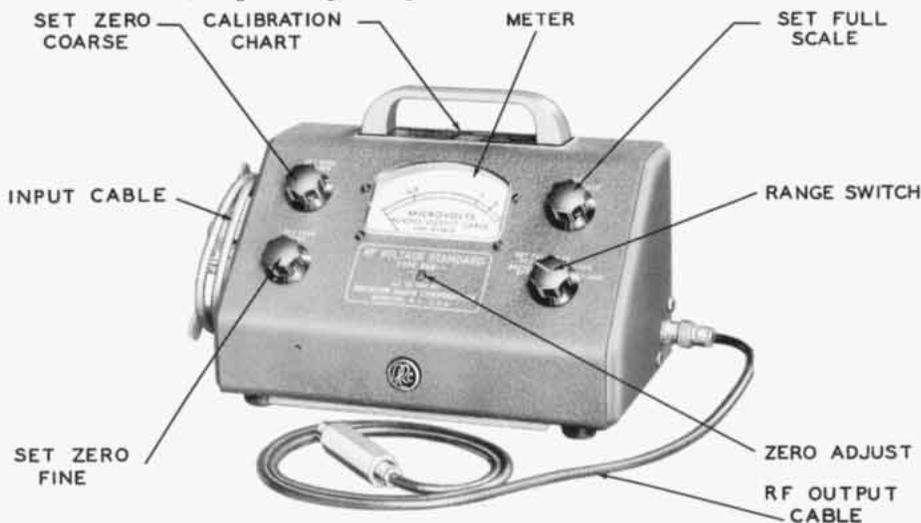


Figure 1. RF Voltage Standard Type 245-A.

An input level of 0.05 volts is established across the input to the coaxial attenuator by adjusting the voltage output of the external rf voltage source until the indicating meter on the RF Voltage Standard reads at the 1 microvolt calibration point on the meter scale with the range switch set to 1 microvolt. The 25,000:1 coaxial attenuator divides the 0.05 volts down to 2 microvolts which appear across the 0.0024 ohm resistor in series with the 50 ohm impedance matching resistor in the rf assembly.

Since the 50 ohm characteristic impedance of the Output Cable is matched by the 50 ohm resistor, its length is electrically indeterminate. In fact, its length may even be considered zero, and the 50 ohm terminating resistor is effectively connected to ground directly from the 50 ohm impedance matching resistor in the RF Assembly. This divides down the 2 microvolts delivered by the

of the BRC Notebook³.

The output impedance of the RF Assembly is 50 ohms, determined by the 50 ohm impedance matching resistor, which is the termination of a specially designed section of coaxial transmission line.^{1, 2} Looking back along the coaxial output cable from the 50 ohm terminating resistor toward the RF Assembly, one sees the 50 ohm characteristic impedance of the cable in shunt across the 50 ohm terminating resistor. The net result of this parallel combination is 25 ohms of resistance which is then built up to the desired 50 ohms by the 25 ohm series Impedance matching resistor located between the terminating resistor and the BNC output jack.

The open circuit output impedance at the output jack on the Output Cable is 50 ohms.

Measuring Receiver Sensitivity

The sensitivity of a radio receiver has been defined by the Institute of Radio Engineers⁴ as the number of microvolts required to produce standard output when applied to the dummy antenna in series with the input impedance of the receiver. For a system consisting of a 50 ohm transmission line system and a 50 ohm receiver, this means that a "1 microvolt receiver" will produce standard output when 1 microvolt is applied across the series combination of the 50 ohms antenna impedance and the 50 ohm input impedance of the receiver. This yields 1/2 microvolt across the receiver input terminals.

Figure 4 shows how this condition is met by the voltage calibration and output impedance characteristics of the RF Voltage Standard Type 245-A. The actual circuit can be reduced to a schematic circuit because the characteristic impedance of the cable is matched at the voltage source as described above. The diagrams show the distribution of voltages and impedances along the circuits for the loaded and open circuit conditions

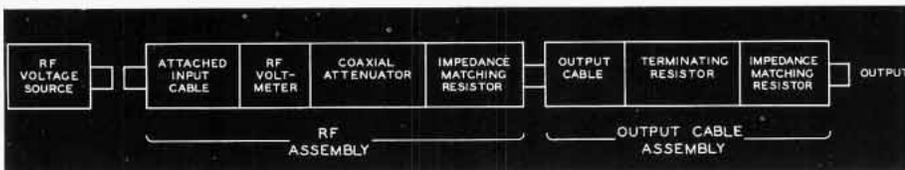


Figure 2. RF Voltage Standard System Block Diagram.

The low voltage output from the RF Assembly, which presents a source impedance of 50 ohms, drives the 50 ohm Output Cable which is terminated by a 50 ohm coaxial terminating resistor. The terminating resistor is followed by a 25 ohm impedance matching resistor to raise the equivalent source impedance at the end of the output cable to 50 ohms.

Output Voltage Calibration

Figure 3 shows the distribution of voltages throughout the instrument when the meter is set at the 1 microvolt level and there is no external load connected to the output cable.

Coaxial Attenuator to 1 microvolt across the 50 ohm terminating resistor.

The meter on the RF Voltage Standard is calibrated in terms of the open circuit voltage appearing across the BNC output jack on the output cable, with no load connected to the cable.

Output Impedance

The output system of the RF Voltage Standard is based on a 50 ohm characteristic impedance. The optimum conditions for power transfer and control of voltage standing waves on the cable as the load impedance is varied are described in the Fall 1954 issue

when the meter indicates 1 microvolt. At this level setting, the circuit is being driven by 2 microvolts out of the Coaxial Attenuator.

The equivalent circuit diagrams show that the same loaded and open circuit characteristics of voltage and impedance will be presented to the load if we assume a simple series circuit consisting of a 1 microvolt generator in series with 50 ohms. This result could have been obtained directly by an application of Thevenin's Theorem to the original circuit. Additional diagrams and explanatory information can be found in the Instruction Manuals for BRC Signal Generator Types 202-B and 211-A, and Uni-verter Type 207-A.

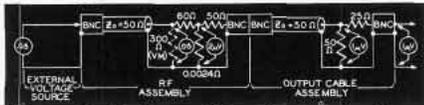


Figure 3. Voltage Distribution for Open Circuit Voltage of 1µV at End of Output Cable.

The sensitivity of a receiver designed to work with a 50 ohm antenna line impedance can therefore be read directly from the meter at 1/2, 1, and 2 microvolts because the equivalent source impedance of the RF Voltage Standard provides the 50 ohms to which 1/2, 1, or 2 microvolts are applied.

If higher values of antenna resistance are involved, direct readings of receiver sensitivity can be obtained by merely adding in series with the output cable a suitably-mounted, non-reactive resistor whose resistance is equal to the desired antenna resistance minus the 50 ohms already presented by the RF Voltage Standard. For example: to read directly the sensitivity of a receiver designed to work from a 75 ohm line, such as RG-11/U, a 25 ohm resistor must be added in series with the inner conductor at the BNC output jack on the output cable to obtain the correct impedance match. If values of antenna resistance less than 50 ohms are involved, it is necessary to use an impedance matching pad and allow for its insertion loss.

Checking Signal Generator Output

The use of the RF Voltage Standard to check the output from a signal generator is based on using a receiver as an un-calibrated

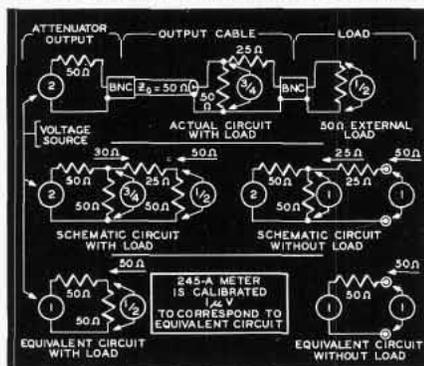


Figure 4. Derivation of Equivalent Circuit of RF Voltage Standard Output System Assuming a Matched Load & 1µV Setting.

transfer indicator to compare the outputs from the two sources at a fixed signal level. Figure 5 shows the steps for the case of a signal generator having 50 ohms output impedance at the output jack.

The method shown in Figure 5, in which the same Output Cable is switched from the RF Voltage Standard to the signal generator output jack is valid only for signal generators having a 50 ohm source impedance at the panel output jack.

Some signal generators, however, present 50 ohms only at the output end of their own special 50 ohm terminated output cable. In this case, the receiver input must be transferred between the terminals of the output cable on the signal generator and the output cable on the RF Voltage Standard. Only in this way will the comparison show up standing wave errors in the signal generator output system.

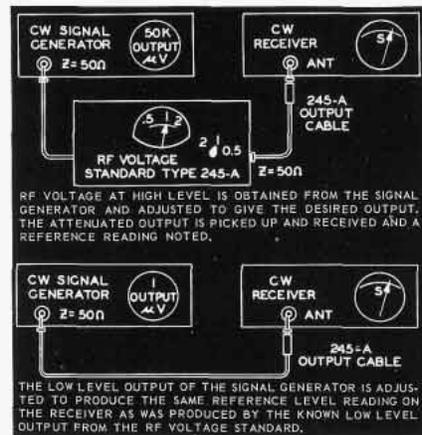


Figure 5. Comparison of Voltage Output from a 50 Ohm Signal Generator with the RF Voltage Standard, Using a Receiver as an Uncalibrated Transfer Indicator.

In case the signal generator has a source impedance of 50 ohms, it is not necessary that the receiver input impedance be matched to the signal generator output impedance to obtain a valid comparative reading. Since the two sources of voltage present the same im-

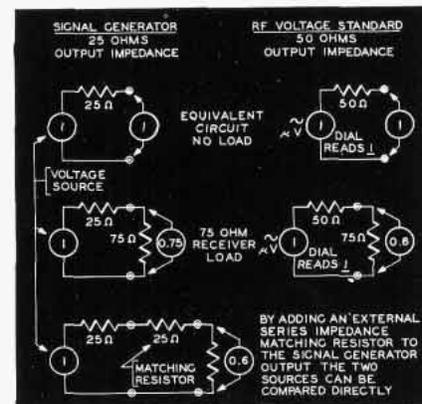


Figure 6. Comparison of Voltage Output from Unequal Source Impedances by Addition of an External Impedance Matching Resistor.

pedance, it is necessary only that the receiver input impedance remains constant, at whatever value it may have, throughout the comparison process. For this reason, only the signal generator frequency can be changed to peak the receiver response, since small changes in receiver tuning may result in appreciable changes in input impedance.

An amplitude modulated signal can be used with an AM receiver and an audio voltmeter, provided the amplitude modulation is kept below 30%.

Unequal Source Impedance

The problems of interpreting signal generator output readings increase when checking the calibration accuracy of a signal generator whose output impedance cannot be made the same as the reference standard by suitable resistive pads, as shown in Figure 6, or whose output cable system sets up standing waves at critical frequencies. These same problems arise in the use of such a signal generator for receiver sensitivity measurements. The necessary information to make these corrections is given in some detail in catalogues and instruction manuals by the major manufacturers of signal generators.

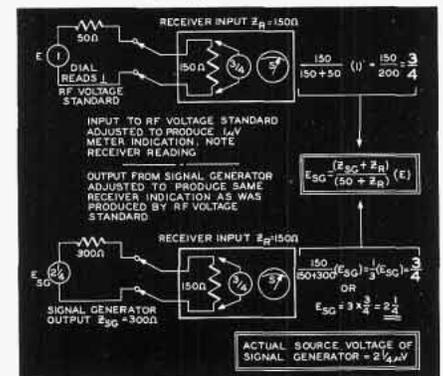


Figure 7. Signal Generator Calibration when all Three Impedances are Different.

Figure 7 shows a case in which the impedances of the RF Voltage Standard, the signal generator and the receiver are 50 ohms, 300 ohms and 150 ohms respectively. The general equation shown in the figure gives the number of microvolts actually delivered by the signal generator for any combination of impedances in terms of the indicated output level of the RF Voltage Standard.

The presence of standing waves in the output system of a signal generator which is not matched internally will produce errors in calibration which must be corrected by using data supplied in the signal generator instruction manual. These errors are a function of frequency and must be taken into account at each frequency setting.

In summary:

1. Determine the output impedance characteristics of the signal generator being calibrated.
2. Attempt to modify it to 50 ohms by the use of pads or dummy antenna systems, taking into account their effect on the calibration due to attenuation characteristics.

3. If the output impedance cannot be made 50 ohms, determine the complex impedance of both the receiver and the signal generator and calculate the resulting voltage divider. Also calculate the voltage divider consisting of the receiver and the 50 ohm impedance of the RF Voltage Standard.

4. Since the outputs of the two voltage dividers are equal when the signal generator output is adjusted to give the same receiver reading as the RF Voltage Standard, we can equate the two expressions as follows: $\frac{Z_r}{Z_r + Z_{sg}} (E_{sg}) = \frac{Z_r}{Z_r + 50} (E)$, where

- Z_r = receiver input impedance
- Z_{sg} = signal generator output impedance
- 50 = RF Voltage Standard output impedance
- E_{sg} = signal generator open circuit voltage
- E = RF Voltage Standard open circuit voltage

Then the signal generator setting, E_{sg} , which will produce the same receiver response as the output of the RF Voltage Standard, E , can be determined from the equation: $E_{sg} = \frac{Z_r + Z_{sg}}{Z_r + 50} (E)$

Use As A 50 OHM RF Voltmeter

The input system of the RF Voltage Standard is shown in Figure 8. It contains a length of coaxial cable which connects the source of power to the coaxial "head," which consists of a diode voltmeter in parallel with the input to the precision coaxial attenuator. The diode voltmeter reads the input voltage directly at the input to the attenuator, and the calibration of the RF Voltage Standard is not affected by standing waves on the cable ahead of this point.

The 60 ohm attenuator input impedance is shunted by approximately 300 ohms diode impedance, which together form approximately a 50 ohm termination for the 50 ohm input cable. The voltage seen by the diode voltmeter at the input to the attenuator will be nearly the same as that applied at the input BNC connector, subject to voltage standing waves on the cable. Variations in the characteristic impedance of the cable and the diode impedance introduce a moderate standing wave of voltage on the cable which increases with frequency.

The ratio for each coaxial attenuator is individually determined, and the correct input voltage for the 1 microvolt level meter setting is given on the voltmeter calibration data plate on top of the instrument. This information can be used for checking the instrument at low frequencies (below 500 kc) and for measuring rf input voltages. With the range switch in the 1 microvolt position, the input voltage is increased until the meter indicates 1 microvolt. The input voltage is then equal to the value stamped on the data plate. Input voltages of 1/2 and 2 times this value can be determined by adjusting the input for meter indications of 0.5 and 2 with the range switch in the corresponding position.

Accuracy

The method of setting up the calibration of the RF Voltage Standard at the factory is such that the initial accuracy is determined

by the care with which the 60 ohm and the 0.0024 ohm resistors are measured, the accuracy of the voltage source used to set up the rf voltmeter circuit, and the Voltage Standing Wave Ratios (VSWR) of the input to the coaxial attenuator and the impedance match of the output cable termination. Of these, the VSWR is the least accurate measurement and also the greatest contributor to the overall tolerance.

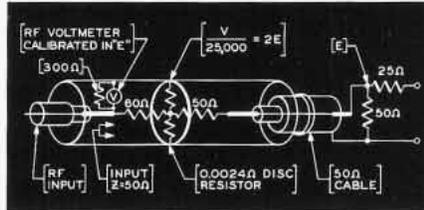


Figure 8. RF Attenuator and Voltmeter.

The 60 ohm film resistor is the center conductor of a terminated transmission line² and together with the 0.0024 ohm disc resistor it provides an accurate attenuator useful over a very wide range of frequencies⁵. The actual ratio is taken into account in setting up the voltage into the attenuator and adjusting the meter to read the desired output voltage. The uniformity with frequency of the attenuation ratio is determined by comparing each unit against a carefully measured standard unit at several points over a wide frequency range.

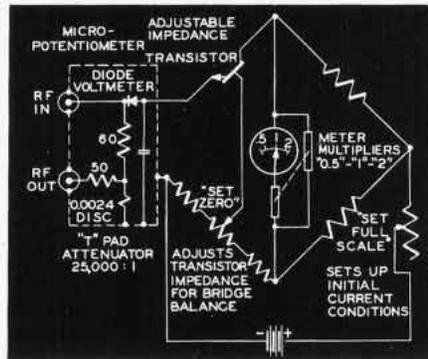


Figure 9. RF Voltage Standard-Basic Circuit.

The long term accuracy, which is of considerably more importance and upon which the specifications are based, includes the stability of several components not involved in the initial calibration. A circuit has been chosen in which these variations are minimized by the procedure used to place the instrument in operation.

The simplified circuit of Figure 9 shows the basic dc metering system associated with the rf voltmeter. The rectification efficiency, or ratio of rectified dc current to applied ac voltage, of a semi-conductor diode at a controlled value of bias current is a very stable characteristic.

The transistor is used in conjunction with the diode to raise the impedance level presented to the meter for proper damping. The diode current passes through the junction transistor with a constant efficiency of about

98% regardless of resistance changes. This current transfer factor, known as "alpha," is very stable and therefore does not contribute any significant variation in accuracy. The action is somewhat analogous to the unity voltage gain characteristic of a cathode follower circuit which also presents a large impedance ratio between input and output circuits.

As seen in Figure 9, the transistor impedance is located in one arm of a bridge. Hence the bridge can be brought to balance by varying the transistor impedance by means of its base voltage. This is done during the initial adjustment procedure with the SET ZERO control. This does not affect the 98% efficiency of current flow through the transistor.

Precautions

Several points of technique in handling low-level radio frequencies become of particular importance when checking the calibration of a signal generator. RF voltage leakage out of the signal generator, sometimes along the power cord, will cause trouble if the receiver is not well shielded. Likewise, interfering signals from adjacent equipment or broadcast transmitters will affect poorly shielded receivers and prevent accurate measurements.

The conditions of impedance match and corrections for standing waves on output cables must be accounted for before the performance of a signal generator can be evaluated. The connections between the output cable from the RF Voltage Standard and the signal generator to the receiver input should be as short as possible. The insertion loss of any matching pads must be included in the comparison.

Sharp receiver response will cause critical tuning and stability problems, and will pass only the low frequency components of the noise which make the meter bounce. A wider pass-band will produce a higher, but much steadier, noise level to which the desired signal is added.

Tune only the signal generator when searching for maximum receiver response to avoid changes in the receiver input conditions.

Always check the signal generator tuning when going from the condition of high level into the RF Voltage Standard to the low level into the receiver. It is sometimes advisable to re-tune the signal generator frequency each time the low level output is re-adjusted in order to get significant results.

When first placing the RF Voltage Standard in operation, it is advisable to re-check the SET FULL SCALE and SET ZERO positions. Initial drift can be caused by changes in battery voltage when the instrument is first turned on and by changes in the resistance of the transistor due to a sudden change in temperature, such as bringing the instrument from storage into a warm laboratory. There is no significant heat developed inside of the instrument. Re-adjusting the SET FULL SCALE and the SET ZERO controls restores the calibration accuracy of the instrument even though the transistor and diode dc resistances may have changed.

Summary

By judicious use of the RF Voltage Standard Type 245-A it is possible to check the low and high level calibration of signal generators over a wide range of frequencies, and to establish signals for testing receivers at the microvolt level with a confidence not formerly possible.

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Calibration of the Internal Resonating Capacitor of the Q Meter

SAMUEL WALTERS, Editor, The Notebook

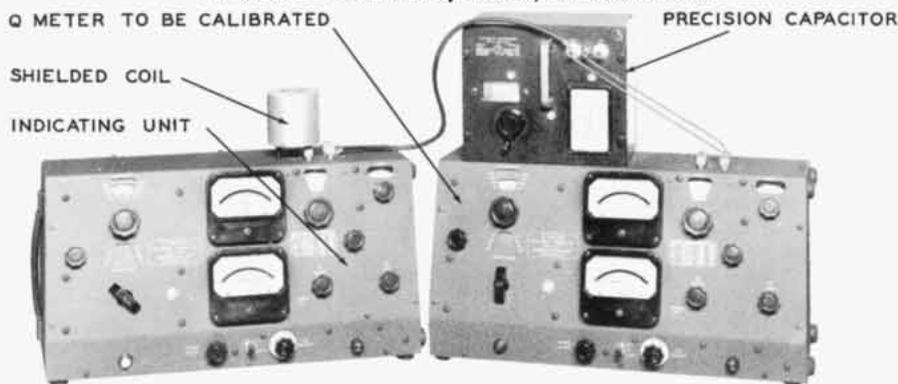


Figure 1. Interconnections of equipment that can be used in the calibration of the internal resonating capacitor of a Q Meter. Here shown are Q Meters Type 260-A and GR precision capacitor Type 722-D.

Recently we have received a number of inquiries on this subject. They are numerous enough to indicate a wide-spread interest in the technique of calibrating the Internal Resonating Capacitor of the Q Meter. This interest is understandable since the versatility of the Q Meter in performing a host of functions besides measuring Q^* depends, in some special cases, on the additional accuracy obtainable from an error curve for the Internal Resonating Capacitor.

The Q Meter contains (1) an RF oscillator, (2) a measuring circuit including the main and vernier tuning capacitors (Internal Resonating Capacitor), (3) a vacuum tube voltmeter and (4) a system for injecting a known amount of the oscillator voltage in series in the measuring circuit.

The Internal Resonating Capacitor is used to adjust the value of capacitance so that the circuit under test can be resonated at the measurement frequency. Calibration of this capacitor should be done at a relatively low frequency with respect to the instrument's operating range in order to prevent stray inductance effects.

The calibration method described here is based on substitution of a known amount of capacitance from a precision capacitor for an indicated amount of capacitance in the Q Meter, using a resonant circuit on a second Q Meter for the comparison.

Equipment Required

- 1 Q Meter to be calibrated—BRC 160-A or 260-A (referred to as No. 1).
- 1 Q Meter (BRC 160-A or 260-A) used as an Indicating unit (referred to as No. 2).
- 1 Precision Capacitor with a range covering at least $600\mu\mu\text{f}$ (G.R. 722 or equivalent).
- 1 Shielded Coil that will resonate between 200-500 KC.

Preliminary Check

Before beginning calibration it is advisable to inspect the Internal Resonating Capacitor to be calibrated. A quick check of the following points may save a needless repetition of calibration and avoid waste of time since the instrument can not be calibrated properly if any of these mechanical conditions prevail:

- (1) Examine capacitor for foreign matter, specks of dirt, etc. Such matter tends to lower the Q of the capacitor by introducing a spurious resistance across it.
- (2) Check main bearing of rotor sections of both main and vernier capacitors. Shafts should be firm to prevent mechanical backlash or electrical instability.
- (3) Check spring gear take-up of both capacitors. Improper loading of gears will also cause backlash.
- (4) Make certain rotors are centered with stators. Check plate spacing visually. Run out rotor plates to notice any wobble.

Procedure of Calibration

- A. Calibration of main Q Capacitor.
 - (1) Set the Q Meter, No. 2, which is to be used as the resonance indicator, to $450\mu\mu\text{f}$ and turn on the power. Mount on the instrument a suitably shielded coil that will resonate between 200 kc and 500 kc such as the 103-A32.
 - (2) Connect the precision capacitor to the Hi and Gnd terminals of the indicating Q Meter through a short piece of coaxial cable. Now set the capacitor in the indicating Q Meter, No. 2, to the minimum value of $30\mu\mu\text{f}$.
 - (3) Connect the grounded terminal of the precision capacitor to the Gnd terminal on the Q Meter being calibrated (No. 1) with a No. 18 stranded copper wire. Arrange another lead from the insulated terminal on the precision capacitor to a point in air $\frac{3}{8}$ " to $\frac{1}{2}$ " above the Hi capacitor terminal post of the Q Meter being calibrated (No. 1) using a no. 20 AWG bare tinned signal conductor copper wire. The tip of this self-suspended lead must be straight, without hooks or loops, and must point down to the Q Meter terminal. Isolate this lead from surrounding objects.
 - (4) Set the precision capacitor to $600\mu\mu\text{f}$ or more. Now adjust the oscillator frequency control of the indicating Q Meter, No. 2, for a maximum indication of Q. Resonance will occur at a lower frequency than in step 1. Note the setting of the precision capacitor, calling the reading C_1 .
 - (5) Set the main capacitor dial of the Q Meter being calibrated (No. 1) to 30 and the vernier dial to zero. Do not energize this Q Meter.
 - (6) Touch the suspended lead, moving it as little as possible, to the Hi terminal post on the Q Meter being calibrated and re-resonate with the precision capacitor. Note this reading as C_2 . The difference between the two recorded readings, $C_1 - C_2$, plus $0.15\mu\mu\text{f}$ is the true capacitance corresponding to a dial reading of $30\uparrow$.
 - (7) Using the reading noted in step 4 as C_1 , other values of capacitance on the

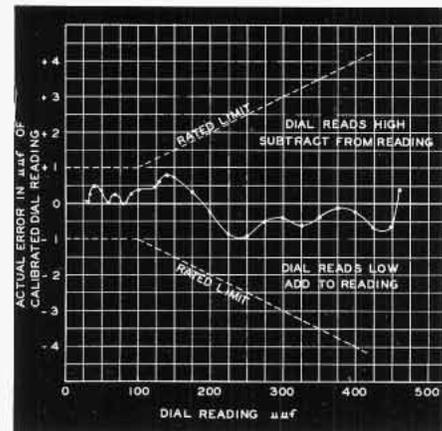


Figure 2. Correction Chart.

Q Meter main capacitor can be checked by successive settings of the unknown capacitor and the precision capacitor as above to obtain new values of C_2 .

B. Calibration of Vernier Tuning Capacitor

The same procedure is followed as above except that the range of the precision capacitor must be expanded to obtain greater accuracy of calibration. The main tuning capacitor is left at $30\mu\text{f}$, and the vernier capacitor is moved successively from 0 to +1, +2, +3, and -1, -2, -3. The amount of change on the precision capacitor dial necessitated in each case for resonance on the indicating Q Meter represents the corresponding value on the vernier capacitor.

By subtracting the calibrated values from the dial readings and plotting the errors against the dial readings as shown in Figure 2, a calibration chart for the main capacitor can be drawn up. It is possible through this method of calibration to obtain an error curve which permits use at an accuracy somewhat better than our specified tolerance[†], depending of course on the skill of the operator and the accuracy of calibration of the precision capacitor used. A similar but expanded chart (since the actual error will be in tenths) can be drawn for the vernier capacitor.

* See lead article in Winter, 1955 issue of Notebook on "A Versatile Instrument—The Q Meter" by L. O. Cook.

† The VTVM adds about $0.15\mu\text{f}$ when the meter is energized for normal Q Meter operation.

‡ Specified accuracy is plus or minus $1\mu\text{f}$ from 30 to $100\mu\text{f}$ and plus or minus 1% above $100\mu\text{f}$.

A NOTE FROM THE EDITOR

We have noticed, as the publication date for each issue of THE NOTEBOOK draws near, that members of our engineering department pause when passing the editorial sanctum on the way to the water cooler and gape over our shoulder at the three-inch layer of chaos spread over the desk. This we charitably attribute to the engineer's curiosity concerning the mysterious journey of The Notebook to the printed page, (rather than wonderment as to why anyone would get paid for doing that sort of thing), and we feel that our readers, members of the same genus, might also be curious, if not in the mechanical process of preparation of THE NOTEBOOK, then certainly in the mystery of why another group of engineers should be so interested.

Dispensing with a description of the blood, sweat and tears generated by the authors in the course of their creative labors (many of our readers are painfully familiar with the picture), we will begin the journey at the point where the copy is ready for typesetting. The type for THE NOTEBOOK is "set" by a monstrous machine called a Linotype, which spews castings, or slugs, each of which corresponds to a line of type. This machine also has the ability to make an even right hand margin by regulating the spacing between individual letters and words.

When the copy has been linotyped and edited as carefully as time and the human factor permit, it is cut up and pasted in page form on large sheets of paper. The larger type used for headings is set by hand, using commercially available pads of paper letters.

Glossy photostats of the line drawings are also pasted in position.

When our eight "repro" pages are ready, we take them to the offset printer, who proceeds to photograph them with a camera which is roughly half the size of a master bedroom. In this photographic process he reduces the size of our repro pages, which have been arbitrarily set up 10% larger than the final page size. The developed negatives are then placed over a light box and all extraneous lines, marks and paste-up details picked up by the camera are removed by means of opaquing fluid. The negatives are then carefully laid out in two rows of four each on a large sheet of paper, each page having a special position with respect to the others. This operation is called "stripping." A large plate of thin, sensitized metal is then exposed to light through this bank of negatives. When the plate is "developed" the exposed areas retain a greasy substance which attracts and holds printing ink. The plate is now mounted on the cylinder of the offset press and rotated, first against ink rollers which deposit ink only on the greasy areas, then against a large rubber roller which, in turn, transfers the ink to the paper passing through the press.

Each sheet of paper, when printed on both sides in what the printer terms a "work and turn" sequence, contains two complete copies of THE NOTEBOOK. These sheets are then fed into a folding machine which simultaneously folds and creates the glued binding. There remain only to cut, trim and punch the loose-leaf holes and our NOTEBOOK is ready for shipment.

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