Permanent Record and Oscilloscope Techniques with the Microwave Sweep Oscillator
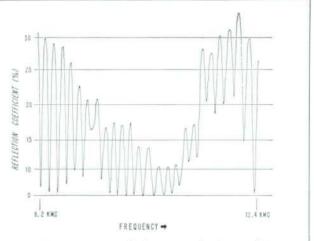
ONE of the basic tools recently made available to the engineer is the voltage-tuned microwave sweep oscillator*. This instrument enables investigation and evaluation of microwave devices and systems to be made with a convenience and speed previously associated only with lower frequency work. The usefulness of the instrument can be seen from the fact that it provides a linear sweep of the full 8.2 - 12.4 kilomegacycle range at sweep rates which are adjustable from 50 sweeps per second to 1 sweep per 140 seconds. A direct-reading control also permits sweeping of portions of the range as narrow as 4.4 megacycles. At the same time power output is adequate for measurement purposes (at least 10 milliwatts at all frequencies), while variations in power

*P. D. Lacy and Daniel E. Wheeler, *A New 8-12 KMC Voltage-Tuned Sweep Oscillator for Faster Microwave Evaluations*, Hewlett-Packard Journal, Vol. 8, No. 6, February, 1957.
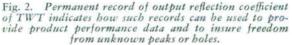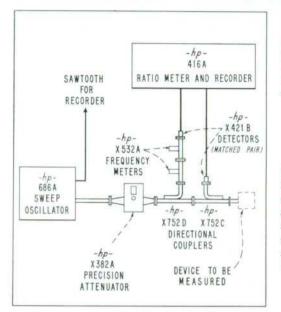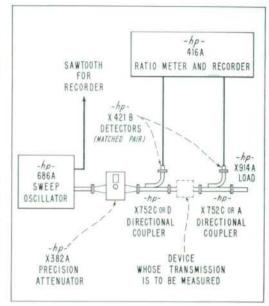
output are moderate. Finally, internal amplitude modulation over a 400 - 1200 cps range is provided for use with auxiliary equipment.

Because of the oscillator's wide range of sweep rates, microwave measurements of reflection, attenuation, gain and other characteristics can be either displayed on an oscilloscope or recorded in permanent form on an X - Y or strip chart recorder. Permanent record measurement, in fact, is proving increasingly popular because of significant inherent advantages. In production work it offers a quick and easy method of providing a customer with a detailed record of product performance and insures that no undesired holes or peaks have been overlooked through use of excessively fast sweeping with restricted bandwidth detection systems. It provides the quality control engineer with comprehensive product data with

Fig. 1.   Besides providing c-w, a-m, and f-m outputs, -hp- Model 686A voltage-tuned oscillator sweeps over full 8.2 — 12.4 kmc range or increments as small as 4.4 mc. Wide range of sweep rates enables measurements to be plotted on recorder or displayed without flicker on oscilloscope. Manual trigger facilitates permanent recording.

Fig. 2.   Permanent record of output reflection coefficient of TWT indicates how such records can be used to provide product performance data and to insure freedom from unknown peaks or holes.

Fig. 3 (a) (at left). *Equipment arrangement for measuring reflection coefficient magnitude in permanent-record form.*

Fig. 3 (b) (at right). *Equipment arrangement for measuring transmission characteristics in permanent-record form. If desired, wavemeters can be inserted as in Fig. 3 (a).*

which he can review production trends. It is valuable for record purposes in proof of performance tests. In the laboratory it provides the development engineer with records which can be incorporated into project notebooks and which can be used for later analysis and for progress evaluation.

A particularly good example of the value of permanent record measurement can be seen in Fig. 2 which shows a record made of the reflection coefficient of the output system of a traveling-wave tube. To investigate such a characteristic by conventional VSWR methods would be prohibitively laborious, while to use tuned detection equipment with fast sweeping and oscilloscope display introduces the danger of compressing responses with consequent optimistic measurement. Later herein, however, a safe technique for making measurements with oscilloscope display will be described.

PERMANENT RECORD MEASURING ARRANGEMENTS

Equipment setups for making permanent record measurements are shown in Fig. 3. Basically, these setups consist of the sweep oscillator in combination with a reflectometer. As a point of special interest it should be noted in Fig. 3 (b) that,

in addition to measuring reflection coefficient, the reflectometer can also be used to measure transmission quantities such as attenuation, gain, and scattering coefficients, since these quantities can also be measured as signal ratios.

In both of these setups an amplitude-modulated swept frequency signal is applied by the Model 686A sweep oscillator to the device under measurement. A known sample of this signal is applied through one directional coupler and broadband detector to one input of the -hp- Model 416A Ratio Meter. A second sample either of a reflected signal (Fig. 3 (a)) or of a transmitted signal (Fig. 3 (b)) is obtained through a second coupler and detector and applied to the second input of the ratio meter. That instrument then forms the ratio of the two signal samples and indicates the ratio directly either in units of reflection

coefficient magnitude or in db of attenuation or gain. The ratio meter further provides a d-c output proportional to its meter reading for operating an external X - Y recorder, although a strip recorder can also be readily used since the sweep of the Model 686A is linear. The sawtooth necessary for operating the horizontal system of an X - Y recorder is provided by the sweep oscillator. The attenuator at the output of the sweep oscillator is used to insure that the power levels at the detectors are not excessive and to optimize the impedance match between the oscillator and the waveguide system.

It is often desirable to be able to insert frequency marker pips in swept-frequency records (see Fig. 5), and this can be done in either setup by inserting reaction type wavemeters as indicated in Fig. 3 (a).

Accuracy-wise, the -hp- waveguide reflectometer system, when calibrated, gives an accuracy of reflection coefficient within ± 0.02 for loads of 0.1 reflection coefficient. On lower reflection coefficient loads, accuracy will be even higher*.

*For additional details, see J. K. Hunton and N. L. Pappas, *The -hp- Microwave Reflectometers*, Hewlett-Packard Journal, Vol. 6, No. 1-2, Sept.-Oct., 1954.
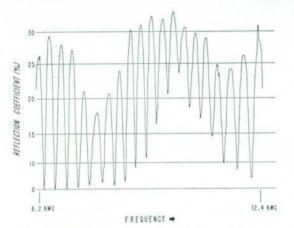

OTHER MICROWAVE SWEEP OSCILLATORS AVAILABLE SOON

Several other microwave sweep oscillators, similar to the Model 686A except for frequency range, have been released for production and will become available beginning early in 1958. The new instruments are:

Model No.	Freq. Range
684A	3.7 - 5.9 Kmc
685A	5.2 - 8.3 Kmc
687A	12.4 - 18 Kmc

See specifications on back page.

Fig. 4. *Permanent record of reflection coefficient of input system of TWT made using setup of Fig. 3 (a).*

Fig. 5. *Record of input and output reflection and of forward and reverse transmission of isolator made using setups of both Figs. 3 (a) and 3 (b).*

LOWER RANGE
CALIBRATION METHODS

Reflectometer systems are probably most often calibrated under swept conditions by adjusting the gain control on the ratio meter so that the meter variations that occur when the system is swept are equally centered around the 100% meter value. When a range lower than the 100% range is to be used, however, it is normally more convenient to have a calibration directly within the range to be used, as is a calibration directly at a go-no go value in such work. If the 30% range of the ratio meter is to be used in making a permanent record, for example, a record of a uniform 30% reflection on the same recording will greatly facilitate later reading of the record,

Fig. 6. *By suitably adjusting gain control on Model 416A Ratio Meter, response of measurement system can be recorded before measuring device under test to facilitate reading of record. Response can be recorded at various levels as shown or at any convenient value. See text.*

since any difference in the responses of the two detectors in the system can be applied directly. In the same way, if a go-no go value of 20% reflection coefficient is to be used, a calibration of the response of the system to a uniform 20% reflection made directly on the recording is of considerable value.

Calibrations at reflection values of any convenient magnitude can be made with only a slight variation of the conventional 100% calibration method. To accomplish this calibration, the reflectometer system should be set up in the customary calibrating manner with a short on its output (and with the two couplers connected directly together if the arrangement of Fig. 3 (b) is to be used). While the oscillator is sweeping and after the output attenuator has been adjusted so that the power level at the detectors does not exceed about —10 dbm, the ratio meter gain control should be adjusted so that meter variations are averaged around the desired value on the meter face when the range switch is in the 100% position. If the desired calibration value lies in either the 10% or 100% range of the instrument, it should be considered to occur on the 0 - 100% meter face scale and the gain control should be adjusted accordingly. If the desired calibration value lies in either the 3% or 30% range, it should be considered to occur on the
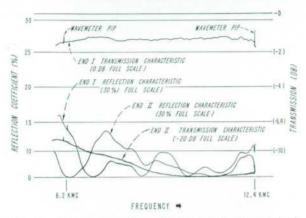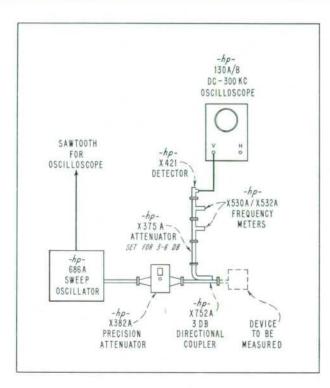
0 - 30% meter face scale. In all cases, however, the ratio meter range switch should be in the 100% position.

To illustrate this procedure with an example, assume that it is desired to establish a calibration of a 20% reflection to use as a go-no go value. Since the value 20% occurs in the 30% range of the ratio meter, the gain control should be adjusted so that the meter variations that occur with sweeping are averaged around "20" on the 0 - 30% meter face scale while the range switch is in the 100% position. If 5% calibration were desired, the gain control would be used to adjust meter variations around "50" on the 0 - 100% meter face scale while the range switch is in the 100% position.

If desired, calibrations can be made at specific reflection increments such as at each 10% point over the desired range to facilitate reading permanent record data even more. Fig. 6 illustrates the types of calibrations that will be obtained with these techniques.

After the gain control has been suitably adjusted for the desired calibration value or values, and after this calibration has been recorded on the recorder, the ratio meter gain control should be readjusted so that the meter variations that occur with sweeping are equally centered around the 100% mark. The system is then calibrated and ready to meas-

Fig. 7. *Fast-response arrangement for measuring reflection with flicker-free oscilloscope display. Internal square wave modulation should be used on sweep oscillator to provide zero reference line on scope.*
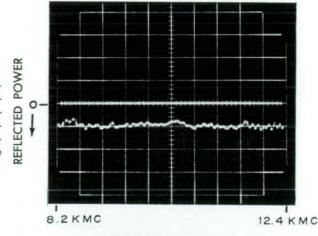
ure and record the response of the device to be investigated with the exception that the ratio meter range switch must now be reset to the actual range to be used (3%, 10%, 30%, or 100%).

The above technique facilitates applying a correction to the measured response for any difference in the responses of the detector mounts which is one of the more significant of the errors in a reflectometer system. The technique does not correct for deviation of the detectors with signal level from a square law characteristic or for the fine structure in the calibration response which represents vector sums of small reflections within the system.

OSCILLOSCOPE TECHNIQUES

The faster sweeps on the Model 686A oscillator are provided so that the instrument can be used to make swept measurements in which the measured value is displayed on an oscilloscope. This type of display is valuable in such work as making adjustments on broadband devices where it is convenient to be able to immediately observe the effect of an adjustment at all frequencies of interest.

When sweeping at the fast rates needed for an oscilloscopic display, it is necessary that the audio or video portion of the system following the detector have a wide bandwidth to avoid reducing the apparent height of peaks and holes. If the bandwidth of the system is not wide, a surprisingly slow sweep rate can cause such reduction. For example, if the fastest sweep rate of the Model 686A (320 kmc/second) is used to display a wavemeter pip with a half-bandwidth of 1 megacycle, the rise time of the pip

Fig. 8. *Typical oscilloscope display obtained when calibrating setup of Fig. 7 using internal square-wave modulation on the sweep oscillator.*

will be about 3 microseconds. For the detector system to display this response accurately requires a detector system rise time of about 1 microsecond or a bandwidth of about 300 kc.

To compare this case with the case of the sometimes-used 60-cycle sinusoidal sweep, it will be found that such a sweep covers the same 8.2 - 12.4 kmc range in 1/120 second or with an average sweep rate that is more than 50% faster than that of the Model 686A. In addition, since the maximum slope of a sinusoid is $\pi/2$ times its average peak-to-peak slope the peak rate of such a sweep will be about 2.5 times that of the Model 686A's fastest linear sweep. Such a sweep thus requires a detector system bandwidth of approximately 750 kilocycles.

A good check on a system is to insure that it adequately displays a wave meter pip, since the high Q's of wave meters impose more demand on the system than will any other device likely to be encountered. All too often, a system will completely obscure such pips.
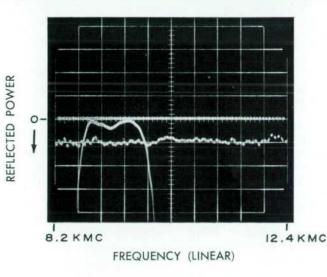
OSCILLOSCOPE DISPLAY SETUP

Fig. 7 shows an equipment arrangement that is both convenient and has sufficient bandwidth for properly measuring and displaying responses on an oscilloscope. Fig. 11, for example, shows clearly how the system displays a wave meter pip.
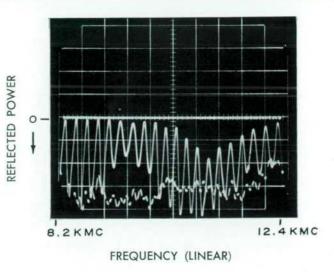
Fig. 9. *Double exposure oscillogram showing system of* Fig. 8 *calibrated for 10% standard reflection and response of typical measuring device — in this case a tuned detector mount.*

Fig. 10. *Same reflection as shown in* Fig. 4 *except as displayed using setup of* Fig. 7.

The setup of Fig. 7 is not a ratio-measuring system, as is a reflecto-meter, but permits the magnitude of reflections to be observed directly as the oscillator sweeps.* The combination of wide bandwidth and high gain needed after the detector element is provided entirely by the -hp- Model 130A/B dc-300 kc oscilloscope which also offers the advantage of being a calibrated amplifier.

In order to calibrate the setup, it must be terminated with a short, while the precision attenuator at the output of the oscillator must be adjusted so that the power level applied to the detector mount is not below about —20 dbm or the amount needed to give an adequate deflection on the oscilloscope. If a 3 db coupler is used and if the suggested 5 db padding is used ahead of the wave meter, the Model 382A precision attenuator at the output of the oscillator will thus be set to insert about 20 db of attenuation following the +10 dbm minimum output level of the sweep oscillator.

When the power level has been adjusted in this manner, an oscillo-

scope pattern like that in Fig. 8 will be obtained. The scope trace across the middle of the oscillogram represents a zero power base line, while the lower trace shows the response of the system and represents a frequency response calibration for the system.
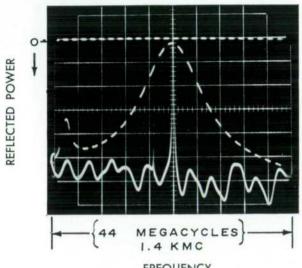
This frequency response calibration can now be made a calibration for any desired value of reflection coefficient such as 50% by suitably increasing the power applied to the system from the oscillator. For example, if the equivalent r-f voltage output from the oscillator is doubled by removing 6 db of attenuation with the precision attenuator, the equivalent r-f voltage applied to the detector mount will be doubled and the calibration in Fig. 8 will be the same as if the system were now terminated with a uniform 50% reflection at all frequencies. If the attenuator setting were reduced by 10 db or 20 db, respectively, the equivalent sensitivity of the system would be increased by 3.16 or 10 times, respectively, and the calibration in Fig. 8 would be the same as if the system were terminated with a uniform 31.6% or uniform 10% reflection coefficient, respectively.

It should be noted that the oscilloscope deflection, in addition to be-

ing negative in polarity because of conventional detector element configurations, will also be a linear power response or square-law voltage response on the face of the oscilloscope.

Figs. 9 and 10 show some typical examples of how this technique is used in making practical measurements. Fig. 9 is a double exposure in which both an equivalent 10% standard reflection and the response of a narrow-band device are compared. The calibration line is used as a go-no go calibration to show the frequency range in which the device has a reflection coefficient of less than 10%. In practice, it is usually most convenient to mark the calibration curve on the face of the oscilloscope with a wax pencil.

Fig. 10 is a double exposure which shows a calibration line and the same TWT characteristic shown in Fig. 4 except as measured using the oscilloscopic presentation. The plot of reflection coefficient magnitude is inverted from that of Fig. 4 by the negative polarity output of the detector element. The dashed line shows an equivalent standard calibration of 31.6%. Since only a 10 db increase in output power is needed for a 31.6% calibration, the initial setting of the precision at-

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*It will readily be seen that, by reversing the coupler and inserting a two-port device ahead of the coupler, the system can also be used to measure transmission quantities of the device. For brevity, however, this discussion is prepared on the basis of measuring reflections.

Fig. 11. *Double exposure oscillogram of resonance characteristic of reflex klystron at two r-f sweep widths. Dashed (square wave modulated) trace has 32 times narrower range than solid trace. Wave meter pip at extreme left of dashed trace has been moved from its position in solid trace so that it is about ½ down skirt of resonance curve, accounting for its apparent lower level in dashed trace.*

loscope graticule.

The resonance dip of the klystron is shown much expanded in the dashed line. Expansions of this type are facilitated by the fact that the Model 686A is provided with a calibrated sweep width control. At the left of the resonance curve in Fig. 11 is a wave meter pip which was used for marker purposes. It can be seen that at the half-power points, the bandwidth of the resonance curve is 14.5 megacycles wide at a center frequency of 10 kmc, indicating a Q of about 700. This agrees within 5% with careful measurements made using wave meters to measure the half-power bandwidth.

As well as checking Q's, this technique is helpful in determining the tuning limits of tunable klystrons or in tuning magnetron cavities.

*— Peter D. Lacy and
Daniel E. Wheeler*

tenuator was adjusted to insert about 15 db instead of 20 db of attenuation so that more deflection results on the oscilloscope. After the standard calibration was made, the attenuator was then adjusted to increase the power applied to the system by 10 db.

In summary, it will be seen that this technique, in addition to offering all of the conveniences of wideband oscilloscopic presentation, overcomes the limitations of systems that have narrowed response and enables accurate measurements to be made on a rapid go-no go basis. In addition, it does this with a minimum of equipment investment, since most of the devices used to form the system are often regular laboratory equipment.

Q MEASUREMENTS

In applications that involve checking or adjusting the center frequency or Q of tuned microwave devices, the oscilloscope technique just described will be found to be of considerable value. Fig. 11, for example, is a double exposure that shows how a Q measurement was made on a reflex klystron. The dashed trace across the upper part of the oscillogram represents zero power level and is obtained by using the internal square wave modulation provided by the Model 686A sweep oscillator. The lower solid trace rep-

resents the response of the klystron over a wide frequency range. In this trace the resonance dip of the klystron appears just coincident with the major vertical axis of the oscil-

Sputnik's Doppler Shift Measured and Recorded with -*hp*- Counter and Digital Recorder

The curve reproduced in Fig. 1 is a high-resolution frequency record made of the 40-megacycle transmission from the Russian earth satellite as it passed over the western United States on Wednesday, October 10. The record was made by the engineering staff of the Stanford Research
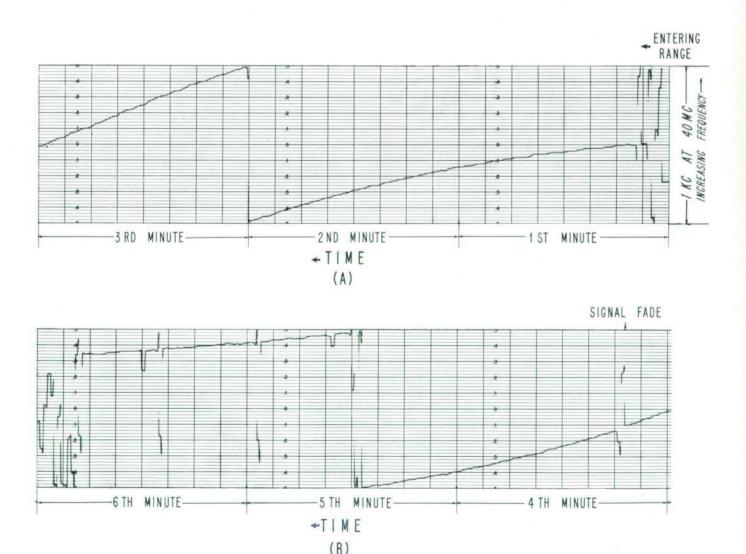

Fig. 1.   *Record of doppler shift in 40-megacycle transmission from Russian earth satellite made by Stanford Research Institute, Menlo Park, California.*
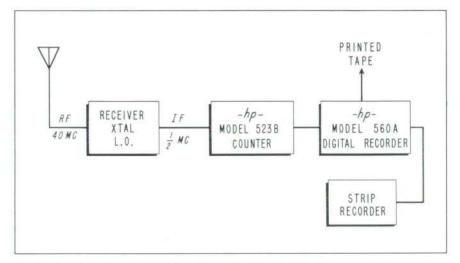
Fig. 2. *Equipment arrangement used to make record in Fig. 1.*

scale value of the record is thus equal to 100 cycles/0.1 second or 1 kc. The resolution of the record then becomes about 10 cycles ($\frac{1}{2}$ of a minor chart division) in 40 megacycles or 0.25 part per million.

The record is actually continuous despite the steps that occur when end of scale is reached. These steps are automatically provided by the Model 560A so that the record will

Institute, Menlo Park, Calif., under the direction of Dr. Allen Peterson, who assembled the system described below and other equipment and established an extensive tracking program shortly after first announcement of the satellite launching.

The record covers a period of some six minutes, during which time the signal happened to be "on" continuously, rather than being keyed. The time scale begins at the right side of the record. Irregular initial readings were caused by low signal strength as the satellite first came into range. The recorded change in frequency after the signal level increased above the noise level is the doppler shift in the received signal. The detailed knowledge of this shift provided by the counter-recorder system enables information to be calculated about the minimum slant range of the satellite with respect to the receiving point as well as about the velocity. At about 3.2 minutes, the signal faded momentarily. After about $4\frac{1}{2}$ minutes occasional fades occurred as the signal level decreased with increasing range. At about $5\frac{1}{2}$ minutes the signal was quite noisy

and was lost shortly thereafter as the satellite passed from range.

The measurement was made with the equipment arrangement shown in Fig. 2. The r-f signal was applied to a receiver with a crystal-controlled local oscillator. The i-f output of the receiver at about 0.5 megacycles was applied to an -hp- Model 523B 1 megacycle frequency counter which in turn operated an -hp- Model 560A Digital Recorder (see *Hewlett-Packard Journal,* Vol. 8, No. 7, March 1957). This instrument both prints counter readings in digital form on paper tape at high speed and provides an analog output for operating a recorder. Although a 1-second gate would give 10 times higher resolution if the signal could be relied upon in advance to be continuous, the counter was operated at a 0.1-second gate in the record of Fig. 1 to insure that readings would be obtained during whatever times the signal were on in the event the signal became keyed or intermittent. The digital recorder was operated so that its analog output was proportional to the final two digits of the measured frequency. The full-

Fig. 3. *Portion of printed tape similar to that provided by -hp- Model 560A during measurement of satellite transmission.*

always be on scale even though the curve exceeds full-scale value.

A printed digital record similar to that shown in Fig. 3 was also provided by the Model 560A for detailed analysis.

Appreciation is expressed to Dr. Peterson and the Stanford Research Institute for permission to reproduce the record shown in Fig. 1.