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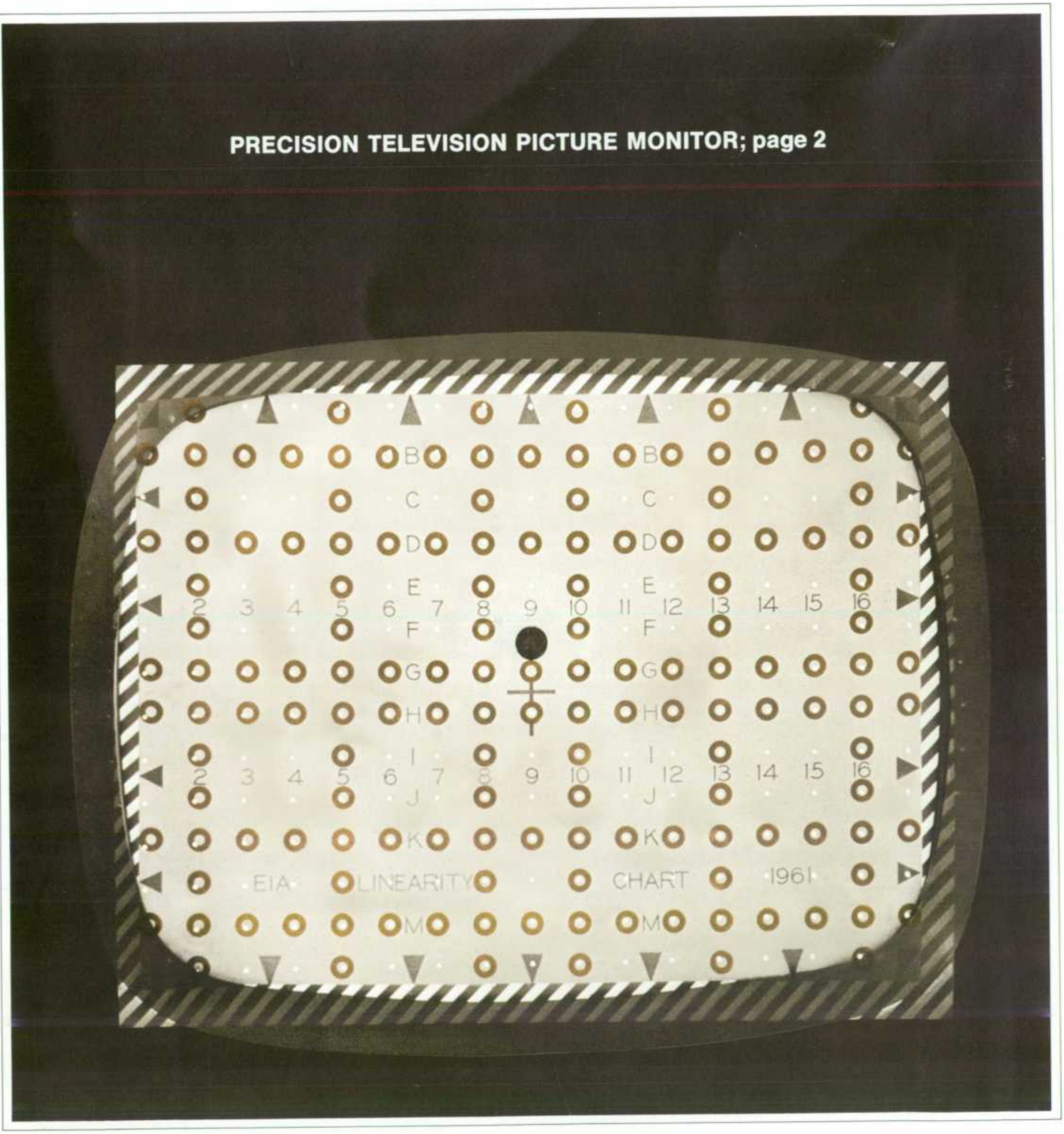

FEBRUARY 1968

A Precision Solid-state Television Picture Monitor

Controlling broadcast picture quality and producing high-resolution, distortion-free, closed-circuit-TV displays are jobs for a precision instrument, like this advanced new TV picture monitor.

By John R. Hefele

Television picture monitors are special-purpose television sets which display picture signals in broadcasting systems and in closed-circuit television systems. They are used in great numbers for broadcast-studio master control, for TV-tape monitoring, for controlling picture quality in studios and in intercity television networks, and for displaying pictures for audiences.

Evaluating and controlling picture quality is a particularly critical application which calls for a particular kind of monitor. To reveal distortion introduced by cameras or transmission facilities without introducing significant distortion itself, such a monitor must have capabilities far beyond those of the system being monitored. It must be able to display television picture signals with an accuracy comparable to that of a precision measuring instrument. Especially important are the monitor's resolution, its frequency and phase responses, its sweep linearity, and its stability.

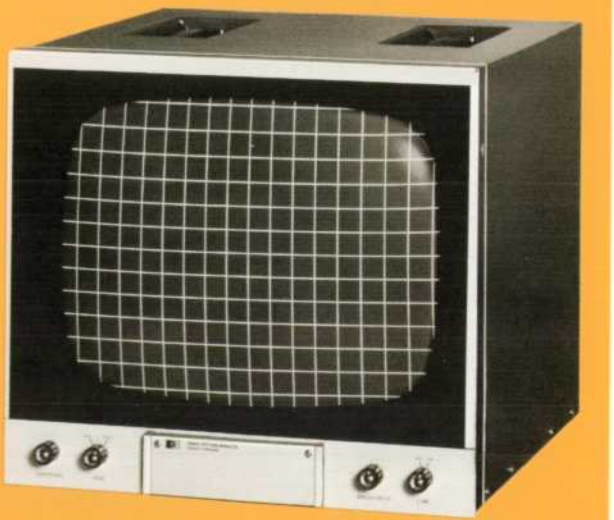

Fig. 1. New HP precision television picture monitor is all solid-state except for picture tube. Circuits use feedback to minimize distortion and maintain stability under wide range of environmental conditions. Instrument shown is Western Electric version, HP Model 6945A. Standard version, Model 6946A, is identical in appearance. Crosshatch display shown here is used for checking distortion and linearity.

Closed-circuit television systems often require a similar type of monitor, that is, one with high resolution and accuracy. This is true, for example, in optical and electron microscopy and in satellite telemetry, or whenever highly detailed and distortion-free pictures are needed.

A new monochrome picture monitor (Fig. 1) has been designed for applications which require a monitor having the quality and stability of a precision measuring instrument. Development of the new monitor was prompted by the Bell System, which asked the instrument industry to develop new and modern monitoring facilities for its intercity television networks. The new monitor represents the second half of a precision television monitoring system, the first half being the HP Model 191A Television Waveform Oscilloscope described in these pages in February 1966.

Circuits are Feedback-Stabilized

The new picture monitor is a low-maintenance, all-solid-state instrument. Owing to the extensive and in some ways unique use of feedback throughout its circuitry, it has a high degree of performance stability under a wide range of environmental conditions.

Frequency and phase responses of the monitor's picture-signal amplifier are carefully controlled, and are feedback-stabilized to make them virtually independent of signal level and of temperature-sensitive active circuit elements. The resulting accuracy and stability make the picture-signal amplifier capable of producing a high-resolution display. To complement the amplifier, a high-resolution 17-inch picture tube is used; its spot diameter is less than 0.010 inch measured at a brightness of 100 footlamberts.

Horizontal and vertical deflection circuits employ feedback to improve and stabilize sweep linearity, thereby keeping the overall geometric distortion of the picture under 1.5%. No linearity adjustments are needed over the life of the instrument. Of special significance is the use of feedback in the horizontal sweep circuits along with the usual energy-conserving sweep technique. It is believed that this is the first time that this has been done in a commercially available picture monitor. It results in an efficient, highly linear deflection circuit.

To permit examination of the edges of the raster, the size of the display can be reduced to 80% of full size by means of a front-panel switch. Linearity is not affected when the display size is reduced, and no other adjustments are necessary.

No Hold Controls

In the synchronizing channel of the new monitor, special circuits regenerate the sync-pulse train to insure stability of the raster (scan pattern), even in the presence of transmission noise. Optimum interlacing of the lines which make up the TV picture is achieved by synchronizing the vertical and horizontal sweeps. No manual hold controls are required for either U. S. or CCIR (International Radio Consultative Committee) scanning standards.

On the Cover: *Geometric distortion of new HP Television Picture Monitor is measured according to IEEE Standards (54 IRE 23.S1). A pulsed luminance signal produces the pattern of bright dots on the screen. The dark 'doughnuts' are projected onto the face of the screen from a distance of five times the picture height, using a 35-mm slide. If the dots are all within the 'holes' of the 'doughnuts,' geometric distortion is 1% or less. The outer edges of the 'doughnuts' are 2% distortion limits. A monitor's distortion must be less than 1.5% to pass the test.*

Also in this Issue: *Measuring Spot Size and Interlace Factor;* ***page 4.*** *Counting CW and Pulsed RF Frequencies to 18 GHz;* ***page 9.*** *Frequency Converter, Transfer Oscillator, or Both?;* ***page 11.*** *'Atomic Second' adopted by International Conference;* ***back cover.***

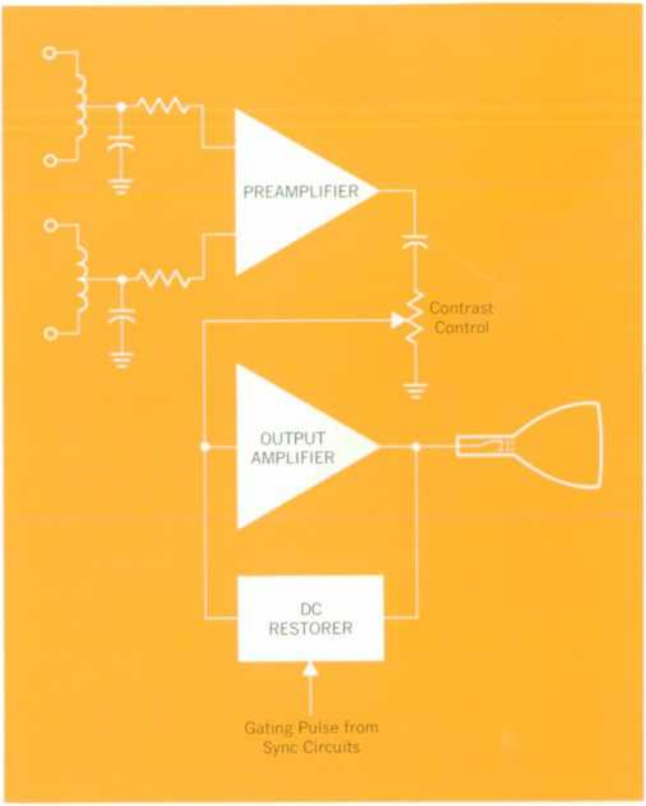

Fig. 2. *Picture amplifier has loop-through balanced or unbalanced inputs for standard television and telephone cables. Dc restorer maintains luminance of displayed black signals constant within 1%. Frequency and phase responses are carefully controlled to avoid distortion.*

High voltage and the lower accelerating-anode potentials required by the picture tube are derived from an all-solid-state high-voltage power supply. This supply is highly regulated (<0.5% voltage change for up to 400 μA output current), so that the size of the raster is not measurably affected by changes in picture-tube current demand. To protect the picture tube, high voltage is cut off when there is no horizontal deflection signal.

Picture Amplifier Requirements

Television picture signals can be considered to be a series of pulses or transients. The amplitudes, widths, shapes, rise and fall times, and times of occurrence of these transients can vary in a completely random manner.

For excellent reproduction of a television picture, the picture amplifier must have carefully controlled transient response. Transient response, of course, involves both amplitude-versus-frequency and phase-versus-frequency responses. However, phase response is especially important. If the picture amplifier doesn't have a linear phase characteristic — that is, if the amplifier doesn't have constant time delay for all frequencies — all of the frequency components of a pulse won't reach the output at the same time. The result is phase distortion, or delay distortion.

The eye's tolerance for delay distortion (phase distortion) is very small. Visually, delay equals displacement. If the picture amplifier doesn't have constant delay for all frequencies, a sharp edge in the original scene may become two edges in the reproduced picture.

On the other hand, the eye has a large tolerance for amplitude distortion produced by an amplitude response which is not flat with frequency.[1] It can readily be shown that the departure from a linear phase characteristic associated with a single uncompensated RC rolloff can produce a more distressing pulse-shape distortion than the accompanying relative amplitude distortion. It seems, therefore, that maintenance of an accurately linear phase shift (constant time delay) over the entire usable spectrum[2] of the picture signal is the main criterion to be satisfied by a good television system.

The picture amplifier of the new monitor has been designed with these considerations in mind.

Picture Amplifier Design

The frequency response of the picture amplifier is flat within ±0.25 dB up to 4.5 MHz, the nominal bandwidth of a television video channel. The response then rolls off smoothly and monotonically to −1 dB at 12 MHz, and to −3 dB at 18 MHz.[3]

The phase response of the amplifier is linear (constant delay) out to frequencies beyond 16 MHz. A T/2 pulse

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[1] Conversely, the ear's tolerance for delay distortion is high, while its tolerance for amplitude distortion is low.

[2] Usable spectrum can be defined as encompassing all frequencies in the picture signal which constitute a detectable, or 'seeable,' portion of the picture. In subjective tests in semi-darkness using good-quality picture monitors, it has been determined that signals 40 dB below the brightest portions of the picture are barely detectable.

[3] Model 6945A, the Western Electric version of the new picture monitor, has an additional seven-pole non-minimum-phase passive network in the picture amplifier. The network gives the amplifier a frequency response which is down 3 dB at 11.5 MHz and down 20 dB at 20 MHz. Both models have the same phase response.

Measuring Spot Size and Interlace Factor

Ultimately, brightness and resolution in the television picture seen by a viewer are determined by the size of the focused spot of the picture tube.

The technique used to measure the spot size of the new monitor is different from the usually employed shrinking raster method. It is also considerably more accurate. Unlike the older method, the new technique gives information about CRT transfer characteristics and, more important, it accurately determines the interlace factor, which is a measure of the uniformity of the spacing between the lines of the raster.*

Measurement Technique Described

A portion of the raster is focused through a microscope onto a small, accurate aperture, 0.125 mm by 6.35 mm. The horizontal scan lines are parallel to the long dimension of the aperture. An optically-filtered photomultiplier is placed behind the aperture, and its output is displayed on an oscilloscope. Once every field time, the luminous spot scans the aperture, producing a pulse in the photomultiplier output. The amplitude of the pulse represents the luminance of the sampled portion of the spot.

An essential part of the technique is to modify the vertical sweep so that a different portion of the spot is sampled each time the spot scans the aperture. A small 2-Hz triangular wave is added to the vertical sweep, causing the entire raster to move up and down three or four millimeters. Since the vertical dimension of the aperture (0.125 mm or approximately 0.005 in.) is less than the spot diameter, the part of the spot that is sampled varies from one side of the spot to the other as the raster moves up and down. The amplitudes of the pulses coming from the photomultiplier also vary, in the same way as the luminance of the spot varies from one side of the spot to the other. Therefore, the envelope of the photomultiplier pulses has the same shape as the spot profile, which is the variation in luminance across the diameter of the spot.

The amplitudes of the pulses displayed on the oscilloscope have been measured, and by means of a curve-fitting technique, it has been determined that the spot profile fits the normal error curve, that is, it has a Gaussian shape (e^{-t^2}).

Spot size, defined as the half-amplitude width of the spot, can be measured on the oscilloscope, provided that the number of millimeters between samples can be determined. This is readily accomplished. The envelope of the displayed pulses is a series of overlapping Gaussian-shaped curves, and the distance between corresponding points of two adjacent Gaussian envelopes is equal to the line pitch of the raster. Line pitch is simply the vertical dimension of the raster divided by the number of lines in it, which is known. Thus the time axis of the oscilloscope can be calibrated in millimeters and the spot size measured.

By this method the spot size of the new picture monitor has been determined to be 0.246 mm (0.00968 inch) at 100 footlamberts displayed brightness, and 0.2318 mm (0.00878 inch) at 30 footlamberts displayed brightness.

Resolution Function

Resolution is defined as the number of distinguishable alternating black and white vertical lines that can be displayed across the horizontal dimension of the picture tube. As the lines become narrower (more lines in same horizontal distance) the brightness range of the reproduced picture decreases. The white lines become less bright and the

* The new technique was suggested in: E. Brown, 'A Method for Measuring the Spatial-Frequency Response of a Television System,' presented at the SMPTE convention in New York, April, 1967 (paper #101-82). As described in these pages, the technique includes additional refinements made by the author.

(a sixteenth-microsecond sine-squared pulse) contains significant frequency components up to 16 MHz. The picture amplifier reproduces a T/2 pulse at the control electrode of the picture tube with greater than 90% amplitude and with a symmetrical shape; preshoot and overshoot are less than 5% and are equal to each other within 1%.

The picture amplifier (Fig. 2) accepts composite picture signals having levels of 0.25 V to 2.0 V and amplifies them to the level required to drive the picture tube.

Two high-impedance loop-through input circuits allow the monitor to accept signals from either balanced or unbalanced transmission lines. The input jacks and their connections to the amplifier are designed to have the characteristic impedances of standard television cables, so they can act as integral parts of the cables. Compensating networks in each input circuit minimize the effects of the input capacitances of the amplifier. The effect of bridging the instrument across a line is quite small; that is, very little power is reflected back into the transmission line. Return loss is greater than 40 dB from dc to 4.5 MHz.

The input preamplifier is a direct-coupled differential-to-single-ended amplifier which has common-mode rejection of 46 dB from dc to 2 MHz. High common-mode rejection is especially important when the monitor is connected to a long cable run. The preamplifier can be driven by two balanced lines or by the shield and center conductor of a single coaxial cable. The open-loop gain of the preamplifier is 140, and is reduced by feedback to a closed-loop gain of 1.8; this amount of feedback provides exceptional stability.

The output stage is a high-efficiency complementary-transistor amplifier stabilized and linearized by feedback for output signals up to 70 V and to over 25 MHz. The complementary transistors allow the circuit to operate linearly over a wide range of amplitudes with a relatively low supply voltage and low power consumption.

black lines become less dark. This happens because the picture-tube spot has finite diameter. As the lines get closer together the spot finds itself trying to reproduce a black line and a white line at the same time; the result is two gray lines.

Aperture characteristics of a picture tube are curves of resolution in TV lines versus relative brightness range in dB. Fig. 1 shows the aperture characteristics of the new picture monitor at two levels of maximum brightness.

Resolution is also related to the frequency response of the monitor's picture amplifier, since for a given scanning rate, the more lines there are in the same horizontal distance the faster the luminance signal alternates between a high value and a low value. Combining the frequency response of the picture amplifier and the aperture characteristics of the picture tube gives an overall 'resolution function' for the new (Model 6945A) picture monitor, Fig. 2. At 650 TV lines, the response is down less than 1 dB. It is down 3 dB at 800 TV lines, 6.5 dB at 1,000 TV lines, and 12 dB at 1,240 TV lines.

It is believed that Figs. 1 and 2 represent the first time such characteristics have been measured and published for any TV monitor. Deriving them required an accurate determination of the spot profile, and this was made possible by the new measuring technique.

Interlace Factor

Interlace factor is defined as twice the smallest separation between adjacent lines of the raster divided by the separation between successive lines at that point. Since the picture is scanned in two fields, and the lines of the two fields alternate on the display, every other line is a 'successive' line. If the fields are perfectly interlaced, the spacing between successive lines will be exactly twice the spacing between adjacent lines, and the interlace factor will be one.

The same oscilloscope display that was used to measure spot size also gives information about interlace factor. Sample pulses produced by adjacent lines of the raster are interlaced on the oscilloscope display in the same order as the lines interlace on the raster. When the new picture monitor was tested, the spacing of the pulses was measured and the interlace factor was found to be exactly equal to one, to the accuracy with which the oscilloscope display could be measured.

Fig. 1. *Aperture characteristics of picture tube in Models 6945A and 6946A Picture Monitors.*
Fig. 2. *Overall resolution function of Model 6945A Picture Monitor is combination of aperture characteristics of picture tube (Fig. 1) and frequency response of picture amplifier.*

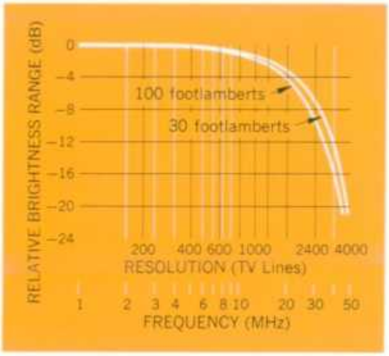

Fig. 1

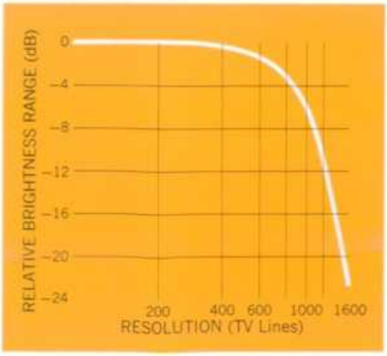

Fig. 2

Black Level Clamped During Back-Porch Interval

A dc restorer in the picture amplifier fixes the luminance of the black portions of the picture at a constant level regardless of the incoming signal level. The dc restorer is a feedback loop (see Fig. 2) which is closed by a sampling pulse during the 'back porch' of the composite picture signal. (The back porch is a short period of blanking level following each horizontal sync pulse. Black level is offset from blanking level by a fixed 'setup' voltage.) This loop effectively reduces the amplification of the circuit to unity for dc and very low frequencies. The stability of the black level is a function only of the regulation of the amplifier's power supply, and this supply is regulated to within 0.05%.

Synchronizing the Picture

To insure an accurately interlaced and stabilized raster, incoming sync signals are given intensive processing and regeneration. Synchronization can be effected either from the composite picture signal, or from one of two external sync signals. A front-panel switch selects which sync signal will be used. Regardless of which source is used, sync signals are given the same processing. The processing eliminates transmission noise, as well as distortion of the sync pulses which may have occurred in long connecting cables.

Incoming sync signals go first through a low-pass filter which reduces their noise bandwidth. They are then clamped by a fast-acting or 'hard' clamp, to remove any low-frequency noise or hum which may have been added to the signal during transmission. Next, the signal is clipped at a predetermined amplitude level; if picture signals are present, they are removed in this step, since the clipping level is near the tips of the sync pulses. The sync pulses are then regenerated by a Schmitt-trigger circuit. The result is a clean, undistorted replica of the incoming sync signals.

Fig. 3 shows the circuits which accomplish these operations. This diagram also shows the remainder of the synchronizing and deflection systems.

Pulses at the line repetition rate (15,750 Hz in U. S., for monochrome signals) are generated by gating the regenerated sync pulses. The gate prevents the horizontal

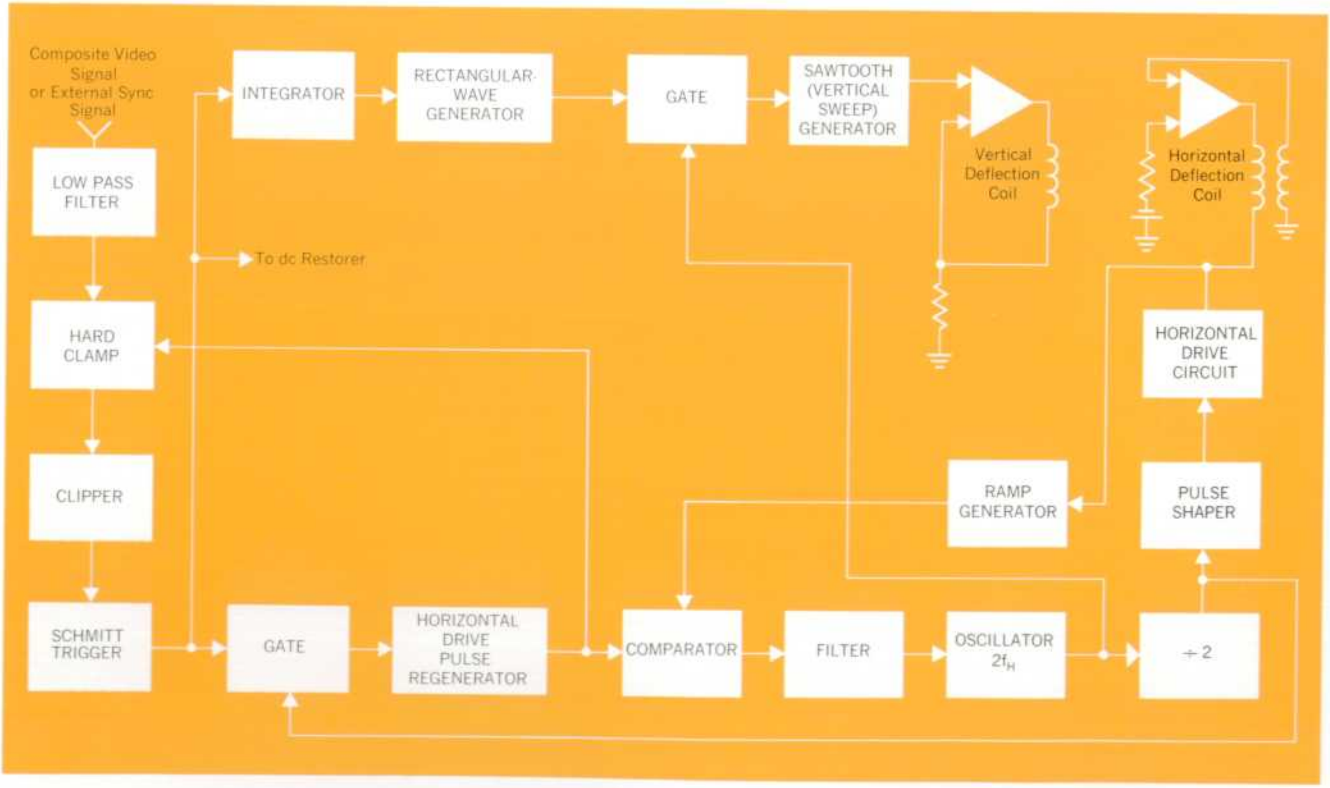

Fig. 3. *Sync circuits regenerate sync pulses to ensure raster stability in spite of transmission noise. Wide lock-in range eliminates need for horizontal and vertical hold controls. Optimum interlacing of fields one and two is assured by triggering horizontal and vertical sweep circuits from same phase-locked oscillator. Sweep circuits have feedback to reduce geometric distortion.*

SPECIFICATIONS

HP Model 6946A
Television Picture Monitor

VIDEO CIRCUITS:

INPUT CIRCUIT: 75 Ω unbalanced to ground; BNC or UHF connectors with loop-through facility.

124 Ω balanced to ground; BNC or UHF connectors with loop-through facility.

Return loss greater than 40 dB from dc to 4.5 MHz.

Protection for up to 100 V peak transients appearing on input balanced line.

Input impedance (unterminated): 12 kΩ.

INPUT LEVEL: 0.25 to 2 volts peak-to-peak for 50-volt signal at kinescope.

COMMON MODE REJECTION (LONGITUDINAL BALANCE): 46 dB from 0 to 2 MHz; decreasing at 6 dB/oct from 2 MHz to 20 MHz.

FREQUENCY RESPONSE: Flat up to 4.5 MHz; decreases monotonically (smoothly) to −1 dB at 12 MHz and to −3 dB at 18 MHz.

SINE-SQUARED RESPONSE: Overshoot symmetry is better than 1% on a 62.5 nanosecond input pulse appearing on the picture tube control grid. Maximum overshoot is less than 5% of pulse amplitude.

RISE TIME: Less than 50 nanoseconds for a step change input viewed at the picture tube modulating grid.

SIGNAL-TO-NOISE RATIO: rms visible noise is more than 50 dB below p-p signal present at picture tube when a 0.25 volt sinusoid is applied to the input.

DIFFERENTIAL GAIN: Less than 3% over specified input level (0.25 to 2 V p-p).

DC RESTORATION: Keyed back-porch clamp.

BLACK LEVEL SHIFT: Less than 1% for a full change in input signal level.

HORIZONTAL DEFLECTION CIRCUITS:

HORIZONTAL AFC: Locks on either 525 or 625 line systems. Horizontal sync is maintained with a composite picture signal-to-noise ratio of 12 dB.

HORIZONTAL WIDTH: More than 5% overscan of the usable visible area of the kinescope; horizontal width control range is 15% of horizontal dimension.

VERTICAL DEFLECTION CIRCUITS:

FIELD RATE: Vertical lock and interlace is automatic. Front panel switch maintains the picture aspect ratio for either 50 or 60 Hz field rate. Vertical sync is maintained with a composite picture signal-to-noise ratio of 12 dB.

VERTICAL HEIGHT: More than 5% overscan of the usable visible area of the kinescope; vertical height control range is 15% of vertical dimension.

DISPLAY:

DISPLAY SIZE: Switchable from 100% to 80% of full picture size *with no change in linearity*.

GEOMETRIC RASTER DISTORTION: Less than 1.5% overall; less than 1% in safe title area (80% of full picture size).

INTERLACE FACTOR: Unity (equal spacing between raster lines).

RESOLUTION: Greater than 650 lines over the entire area of the raster.

LINE BRIGHTENING: Separate raster line brightening input. A line brightening gate produced by a TV Oscilloscope can brighten any selected raster line (1-525) on TV Picture Monitor.

PICTURE TUBE: 17-in rectangular tube, type 17DWP4 with medium short persistence P-4 phosphor, aluminized.

SAFETY GLASS: Circularly polarized laminated safety glass is standard on all units. Polarization increases reproduced picture contrast.

OTHER SPECIFICATIONS:

EXTERNAL SYNC INPUTS: Switch selects Sync 1, Sync 2, or Internal sync inputs (loop-through) at rear of unit. Sync input range is 1 V to 8 V.

TEMPERATURE RATINGS: Operating: −20°C to +55°C. Storage: −20°C to +75°C.

ALTITUDE: Operating: up to 15,000 ft.
Storage: up to 50,000 ft.

CONTROLS:

FRONT-PANEL, EXPOSED: Off-On ac Switch, Contrast, Brightness, Size Switch.

FRONT-PANEL, CONCEALED: 50/60 Hz Field Aspect Ratio Switch, Focus, Height, Width.

INPUT POWER: 105–130/210–260 volts, 50–400 Hz, 75 W nominal.

DIMENSIONS: 17 7/16 in wide x 15½ in high x 20⅛ in deep (44,3 cm wide x 39,4 cm high x 51,1 cm deep).

RACK MOUNT: Rack mounting kits are provided with each unit.

WEIGHT: Net, 63.5 lbs. (30,6 kg).

PRICE: $950.00.

ANTI-REFLECTIVE OPTION: The circularly polarized safety glass, which is standard on all units, may be ordered with a special anti-reflective coating. This coating eliminates most of the surface glare that detracts from easy viewing. Contact your local HP Sales Office for further information.

OPTION 46: Switchable Pulse Cross Display, **$45.00** additional. The Pulse Cross Display presents a rapid and simple method of checking the relative phasing and duration of the synchronizing information transmitted with the video signal.

MODEL 6945A: This is a specially designed 17" monitor for the Bell System. It has Western Electric input jacks located on the lower left rear side panel. This unit does not provide external sync or retrace blanking as provided on the 6946A. It is a companion unit to the HP 193A.

PRICE: $1350.00.

MANUFACTURING DIVISION: HP HARRISON DIVISION
100 Locust Avenue
Berkeley Heights,
New Jersey 07922

drive circuits from being activated by equalizing pulses, vertical sync pulses, or excessive noise pulses. The output of this gate triggers another pulse generator, to produce a train of pulses of uniform width and level occurring at the line repetition rate even during the vertical sync interval.

Phase-Locked Oscillator Drives Both Deflection Circuits

Stability of the displayed picture and correct interlacing of the two fields of each frame are assured by driving the horizontal and vertical deflection circuits with a single oscillator, which is phase-locked to the incoming sync signals. The oscillator operates at twice the line repetition rate, and its output frequency is divided by two to drive the horizontal deflection circuits. The reason for the double-frequency oscillator is that correct interlacing of the two fields requires accurate half-line timing; the vertical scan for field 2 must be started after precisely 262½ lines of field 1 have been scanned.

To phase-lock the oscillator to the incoming sync signals, a ramp of voltage, generated by the voltage appearing across the horizontal deflection coil during retrace time, is compared with the regenerated horizontal sync pulses. Errors in the timing of the retrace cause the comparator output to be above or below zero volts, and this error voltage is used to control the frequency of the oscillator. Lock-in range of the system is such that no manual adjustments are ever required, even if the signal is shifted from the 525-line, 60-fields-per-second U. S. system to the 625-line, 50-fields-per-second CCIR system.

Vertical Sync and Deflection Circuits

The stabilized double-frequency pulses from the phase-locked oscillator trigger the vertical sweep generator. At the start of each field, a train of wide, closely spaced, vertical-sync pulses occurs in the incoming sync signal. An integrator detects their presence and opens a gate, allowing the double-frequency pulses to reach the vertical sweep generator. The first pulse through the gate triggers the vertical sweep. The proper time relationship between the horizontal and vertical sweep rates is preserved, and interlacing of the two fields is nearly perfect (Fig. 4).

Vertical sweep voltages are produced by a Miller-rundown sweep generator. When no sync signal is present, this circuit regenerates itself at a rate lower than 50 Hz. When a sync signal is present, the circuit becomes synchronized with it. This circuit drives the vertical deflection coil of the picture tube through a direct-coupled feedback amplifier. Feedback voltage is derived from a resistor in series with the coil. The regulated power supply for the sweep generator and amplifier is filtered and carefully isolated to keep ripple and crosstalk from degrading the interlace accuracy.

Horizontal Deflection Circuit

Horizontal sweep voltages are generated by a deflection circuit which is triggered by the stabilized pulses from the phase-locked double-frequency oscillator. The

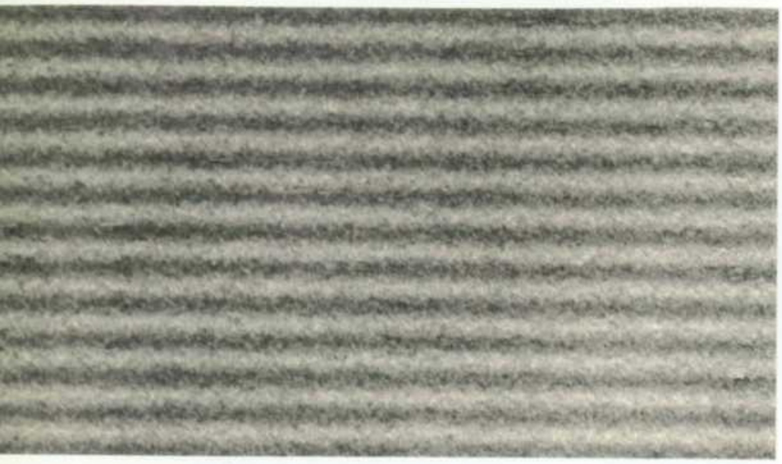

Fig. 4. *Unity interlace factor means spacing between adjacent raster lines is constant.*

oscillator's output is divided by two, shaped, and applied to a transistor switch to trigger the deflection circuit.

To linearize the sweep produced by this circuit, feedback has been used. A sampling winding has been wound together with the deflection coil on the deflection yoke. If the sweep-current change is constant (i.e., the sweep velocity is constant) a constant voltage is induced across the sampling winding; if the sweep current is not changing linearly, the induced voltage is not constant. Comparing the voltage induced across the monitoring coil with that of a reference voltage produces an error voltage proportional to the departure of the sweep current from its proper value. This error voltage furnishes the input to a feedback correction amplifier whose output current flows into the deflection coil and substantially cancels the nonlinearities of the current switching system. Exceptional current linearity is thus obtained. Deviations from linearity are less than ±0.02%, the limit of measurement.

Practically, a small amount of deliberate nonlinearity must be introduced into the horizontal deflection current to compensate for the curvature of the faceplate of the picture tube. For this purpose, a small parabolic voltage is added to the input of the correction amplifier.

The linearity of the sweep currents keeps the geometric distortion of the raster below 1.5% overall, and under 1% in the safe title area (80% of full picture size).[4]

Polarizing Filter Improves Contrast

To reduce the effects of ambient light on the displayed picture, a quarter-wave polarizing filter has been included in the safety-glass cover of the monitor's picture tube. Without the filter, the principal effect of ambient screen illumination is to 'fill up' the shadows, or 'flatten' the tones in the low-level areas of the picture. In areas where the luminance of the picture is below that produced by the ambient light alone, the tube appears to be completely cut off and no detail can be seen.

The polarizing filter reduces by more than 90% the ambient light reflected by the white fluorescent screen. Reproduction of shadow areas with the filter in place is astonishing; there is a very evident increase in contrast and resolution.

The safety-glass polarizer is easily removed for cleaning the face of the picture tube.

Acknowledgments

It has been my pleasure to be associated with the engineers of the Hewlett-Packard Company in the design of the new precision picture monitor. Dr. Bernard M. Oliver's ideas and suggestions were particularly valuable. Electrical design of the monitor was initiated at the HP Laboratories in Palo Alto by Richard E. Monnier and Gregory Justice, and was completed at the HP Harrison Division by Robert E. Lynn, Norman N. Nardelli, and John F. Blokker, engineering manager. James A. Burns and Henry E. Schade did the mechanical design.

John R. Hefele

Now a consultant to Hewlett-Packard, John Hefele was formerly associated with Bell Telephone Laboratories for 43 years. He began doing research in television transmission in 1925, and took part in the first public demonstration of television from Washington to New York in 1927. He continued to develop television circuits and tubes until World War II, during which he worked with military radar and infrared systems. After the war he returned to television research, investigating the problems of visual transmission over restricted-bandwidth channels. Most recently, he was concerned with improvements in television transmission quality and specifications for modern picture monitors, waveform oscilloscopes, and test signal generators. He holds 14 patents.

Mr. Hefele has served since 1948 on the IEEE Video Techniques Committee; he was its chairman for several years. He has also served on various television committees of the Electronic Industries Association and the Society of Motion Picture and Television Engineers. He was elected a Fellow of IEEE in 1965.

Mr. Hefele is also interested in photography. For many years he lectured and acted as technical advisor to motion picture groups.

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[4] Geometric distortion is defined in IRE Standard 60 IRE 17. S1 (IRE Proceedings, June 1960). Its measurement is described in IRE Standard 54 IRE 23.S1 (IRE Proceedings, July 1954).

Counting CW and Pulsed RF Frequencies to 18 GHz

A new frequency converter plug-in and a new transfer oscillator plug-in put frequencies as high as 18 GHz within the reach of electronic counters. This article gives details of the new transfer oscillator, and tells how to make CW, pulsed RF, and FM measurements with it.

By Glenn B. DeBella

Equipped with either of two new plug-in instruments — a transfer oscillator or a frequency converter — several types of HP electronic counters can now measure frequencies as high as 18 GHz. The transfer oscillator operates from 50 MHz to 18 GHz, the frequency converter from 8 GHz to 18 GHz.[1]

The basic principles and relative advantages of the converter and transfer-oscillator methods are compared on page 11.

Except for its tuned cavity and mixer, the new frequency converter is identical to its 3-to-12.4-GHz counterpart which was described in these pages in September 1966.[2] Consequently, the new converter will not be elaborated upon here. Its specifications appear on page 15.

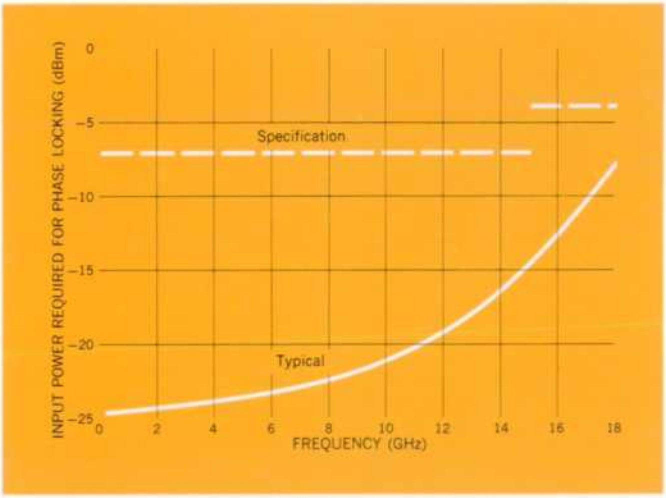

Fig. 1. *The new HP Model 5257A Transfer Oscillator, a plug-in for several HP electronic counters, phase-locks reliably to input signals as small as −24 dBm at 50 MHz and −8 dBm at 18 GHz.*

The transfer oscillator is an entirely new instrument. Together with a counter which will measure frequencies from dc to at least 50 MHz, it forms a dc-to-18-GHz digital frequency-measuring system. It can measure pulsed-RF carrier frequencies as well as CW frequencies.

Instead of the harmonic mixer and phase detector of the conventional phase-locking transfer oscillator, the new plug-in uses a wideband sampler[3] — a new technique for transfer oscillators. It gains several advantages from this substitution. It has greater sensitivity, especially at high frequencies, and it has wider bandwidth than comparable conventional instruments. What's more, its phase-lock loop doesn't need a frequency offset to derive phase information. The loop operates with a zero-frequency IF. Therefore, no offset frequency has to be added to the counter reading, and there are no image responses.

For CW frequency measurements, the transfer oscillator phase-locks a harmonic of its internal variable-frequency oscillator (VFO) to the unknown signal. Phase locking is used even when there is relatively high FM on the input signal. Once the harmonic number is determined (see page 13), it can be set on front-panel thumbswitches and the counter will read the unknown frequency directly, to eight significant figures.

The automatic phase control (APC) lock range for CW signals is approximately ±0.2% of the input signal frequency, quite large for this type of instrument. Lock range is defined as the largest unlocked frequency difference between the input signal and a harmonic of the VFO for which the phase-lock loop will remain locked.

Reliable phase locking is achieved for input signals as small as 100 to 140 mV rms (—7 to —4 dBm into 50 Ω), according to specifications. Typical instruments are much more sensitive, especially at low frequencies, where signals as low as —24 dBm can be measured. Fig. 1 shows specified and typical signal levels required.

In pulsed carrier measurements, the transfer oscillator is tuned until a harmonic of its VFO frequency zero-

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[1] The transfer oscillator is Model 5257A. The frequency converter is Model 5256A. The counters are Models 5245L, 5245M, 5246L, and 5247M.

[2] John N. Dukes, 'A Plug-in Unit for Extending Counter-Type Frequency Measurements to 12.4 GHz,' **'Hewlett-Packard Journal,'** Vol. 18, No. 1, September 1966.

[3] Wayne M. Grove, 'A dc to 12.4 GHz Feedthrough Sampler for Oscilloscopes and Other RF Systems,' **'Hewlett-Packard Journal,'** Vol. 18, No. 2, October 1966.

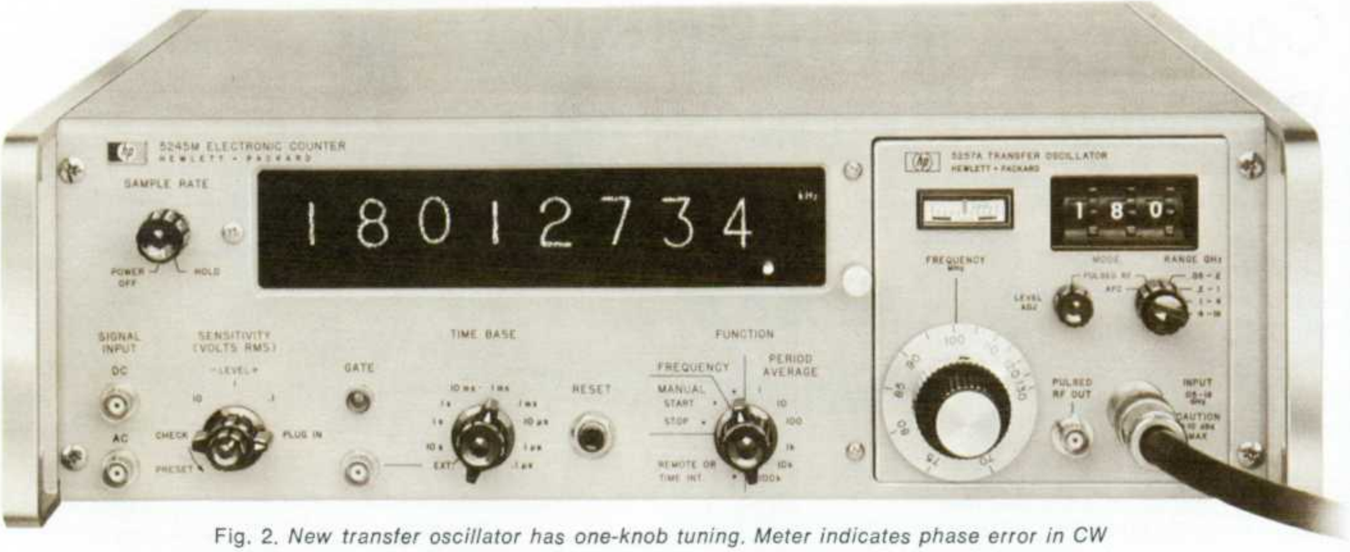


Fig. 2. *New transfer oscillator has one-knob tuning. Meter indicates phase error in CW measurements, detects zero beat in pulsed RF measurements. Thumbswitches extend counter gate time by harmonic number so counter reads unknown frequency directly.*

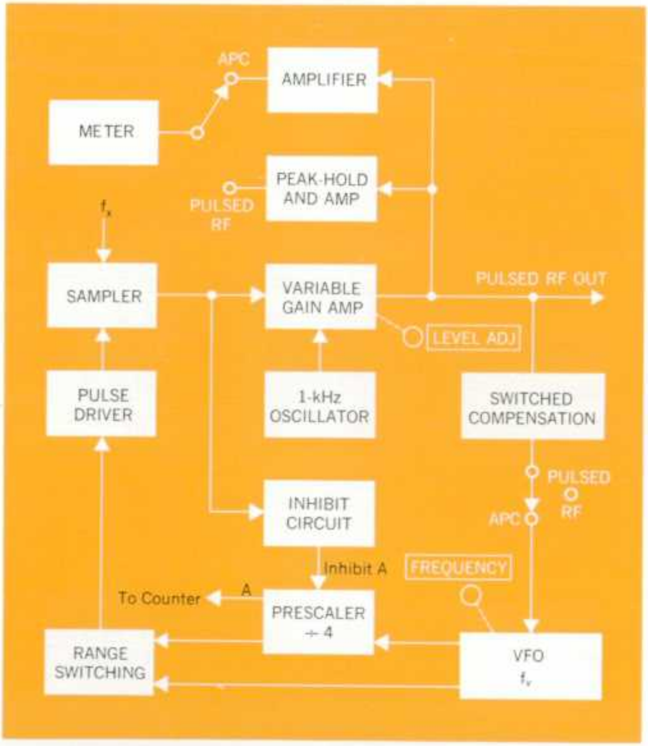


Fig. 3. *Phase-lock loop in new transfer oscillator operates with zero-frequency IF, using wideband sampler instead of conventional mixer and phase detector. Inhibit circuit prevents false counter readings in absence of phase lock.*

beats with the input signal. The transfer oscillator's front-panel meter serves as a zero-beat detector, replacing the complex oscilloscope patterns formerly encountered in pulsed RF measurements. The instrument gives reliable results for pulses as narrow as 0.5 μs. The minimum pulse repetition rate is 10 pulses per second. As with CW signals, the counter reads the unknown frequency directly once the harmonic number is set.

Measuring CW Frequencies

Measuring the frequency of a CW signal with the new transfer oscillator takes five steps.

- Set the frequency range on the RANGE switch (see front-panel photograph, Fig. 2);
- Turn the MODE switch to PULSED RF, tune the FREQUENCY knob for a maximum reading on the meter, and then adjust the LEVEL ADJ knob until the meter reads 0.9;
- Turn the MODE switch to APC and tune the FREQUENCY dial until the counter reads something other than all zeros and the meter reads mid-scale;
- Determine the harmonic number;
- Set the harmonic number on the thumbswitches and read the frequency on the counter.

What happens in each of these steps can be seen in the block diagram, Fig. 3. The RANGE switch optimizes the phase-lock-loop compensation for each frequency range.

Frequency Converter, Transfer Oscillator, or Both?

Two widely used devices for extending the upper frequency limits of electronic counters are the heterodyne frequency converter and the transfer oscillator. Each has its advantages.

Frequency Converter

The frequency converter translates an unknown high-frequency signal downward in frequency by mixing it with a precisely known signal of slightly different frequency. The resulting difference-frequency signal is counted by the electronic counter. Then, if the known signal is lower in frequency than the unknown, the counter reading is simply added to the known frequency to find the unknown. If the known frequency is higher than the unknown, the counter reading is subtracted from the known frequency.

In several HP converters, precisely known frequencies to be mixed with the unknown are produced by applying the output of a quartz-oscillator frequency standard to a harmonic generator. A calibrated tuned cavity is used to select the harmonic nearest in frequency to the unknown.

Transfer Oscillator

Like frequency converters, transfer oscillators also mix the unknown signal with a harmonic of an internally generated signal. However, the internal signal is derived from a variable-frequency oscillator rather than from a frequency standard, and the electronic counter measures the frequency of the VFO signal. The VFO is tuned until a zero beat occurs in the mixer output. Then an appropriate technique (see page 13) is used to determine which harmonic gave the zero beat. The counter reading multiplied by the harmonic number gives the unknown frequency.

If the transfer oscillator provides a means for extending the counter's gate time by the harmonic number, the counter can read the unknown frequency directly. Some transfer oscillators also have a phase-lock loop to maintain the zero beat even if there is relatively large frequency modulation on the unknown. (The new HP Model 5257A has both a phase-lock loop and gate-time extension circuits.)

Techniques Compared

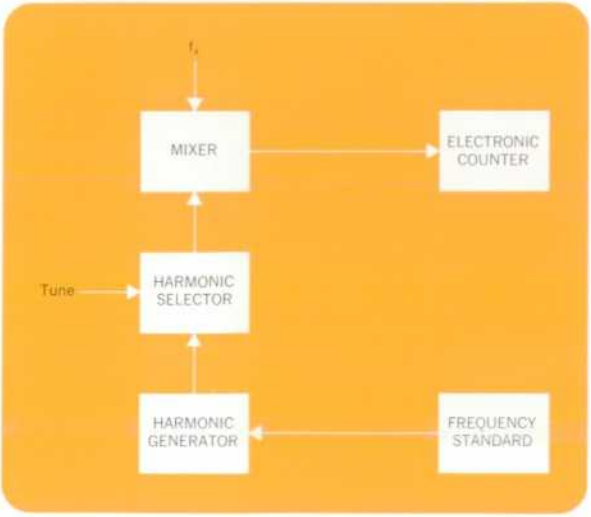
Transfer oscillators have the advantage of:

- Direct readout of the unknown frequency on the counter (if the transfer oscillator has gate-time extension circuits);
- Ability to measure the carrier frequency of a pulsed RF signal;
- Very wide bandwidth
  (For example, the new HP 5257A Transfer Oscillator operates from 50 MHz to 18 GHz, whereas the new HP 5256A Frequency Converter operates from 8 GHz to 18 GHz.)

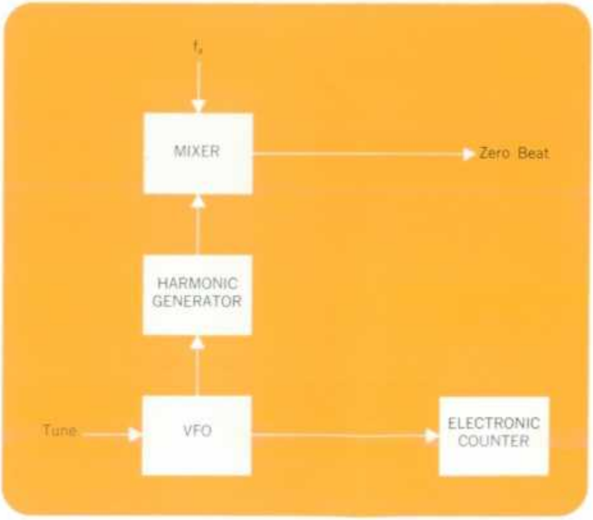
Frequency converters have the advantages of:

- Faster and easier operation, at least when the unknown frequency is completely unknown, so that the transfer-oscillator harmonic number would have to be determined.
- Better resolution
  (The new HP 5256A Frequency Converter gives 1-Hz resolution. For example, in measuring 15.482 973 581 GHz, the converter's dial will read 15.4 GHz and the counter will read 82973.581 kHz. The new HP 5257A Transfer Oscillator, measuring the same frequency, would produce a counter reading of 15.482 973 GHz, giving a resolution of 1 kHz.)

Both the transfer oscillator and the frequency converter will handle signals with high FM. The two instruments are comparable in price.



Basic frequency converter



Basic transfer oscillator

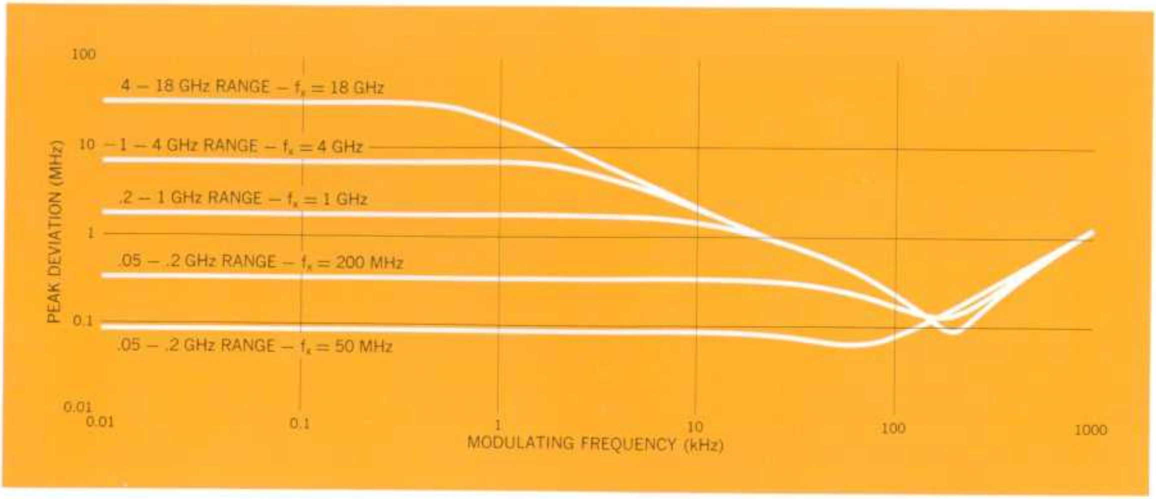


Fig. 4. *Phase-lock loop remains locked to FM signals having peak frequency deviations and modulation frequencies indicated. For example, if input signal has carrier frequency f_x = 18 GHz, loop will remain locked for sinusoidal FM of frequency 20 kHz and peak deviation 1 MHz. If modulating frequency is only 300 Hz, peak deviation can be 30 MHz.*

The LEVEL ADJ control varies the gain of an amplifier to compensate for differences in signal levels.

The wideband sampler serves as a mixer and phase detector. In the three highest RANGE positions, 0.2 to 18 GHz, input signals are sampled at the VFO frequency, f_V. In the 0.05-to-0.2-GHz RANGE position, the sampling frequency is $f_V/4$.

In the APC mode, the phase-lock loop is closed so that a harmonic of the sampling frequency can be phase-locked to the input signal. Phase lock is indicated in two ways. In the absence of phase lock, the counter reads all zeros and the meter remains stationary at mid-scale as the VFO frequency is changed. When phase lock is achieved, a counter reading is present and the meter deflects to the left or right of mid-scale as the VFO frequency is changed. Under phase-locked conditions, the sampler output is a dc voltage proportional to the loop phase error. Thus the meter indicates phase error with mid-scale corresponding to zero error. Therefore, once phase lock has been established, the VFO should be tuned for mid-scale meter deflection.

To keep the counter from giving readings in the absence of phase lock, a low-level 1-kHz signal is injected into the phase-lock loop. Its absence in the sampler output indicates the absence of phase lock, and an inhibit circuit turns off the signal going to the counter.

For input signals having sinusoidal FM, the maximum peak deviations at various modulation rates for which phase lock can be achieved are shown in Fig. 4. At high

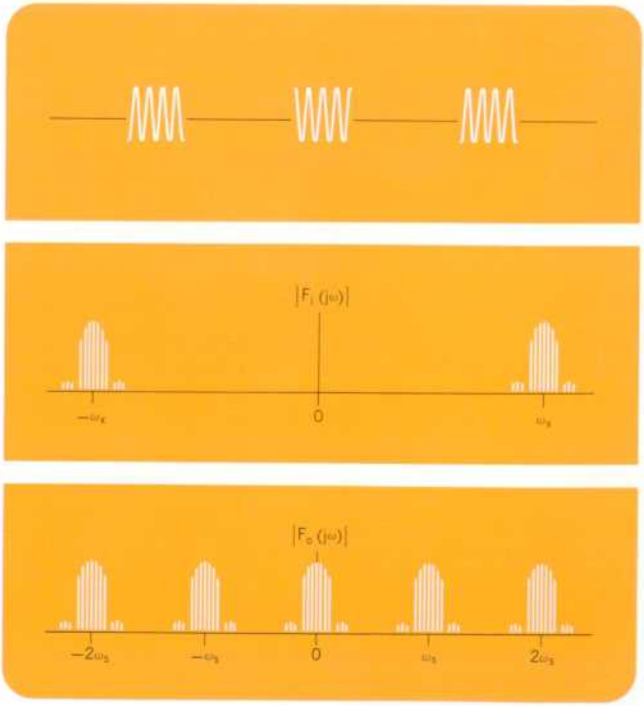


Fig. 5. *Top: a pulsed RF signal. Middle: its frequency spectrum. Bottom: spectrum of sampler output when pulsed RF signal is sampled by an infinite impulse train. Carrier frequency of pulsed RF signal is measured by observing spectrum centered at $f \approx 0$ and tuning transfer oscillator for zero beat.*

input frequencies and low modulation rates, the loop will lock to FM signals having peak deviations in the tens of megahertz.

To obtain the resolution needed for tuning the VFO, a high-reduction gear train was designed. The gear train has two concentric controls — coarse and vernier — and a concentric dial which indicates VFO FREQUENCY. When the vernier input is used, the reduction ratio is 636:1. For coarse tuning, the reduction ratio is 63.6:1. Spring-loaded anti-backlash gears are used. The VFO frequency setting can be repeated reliably within 1/20 degree at the vernier input shaft; this corresponds to a few parts in 10^7 in frequency.

Determining Harmonic Number

The technique used for determining harmonic number is essentially the same for either pulsed RF signals or CW signals. If the input carrier frequency is known to within the sampling frequency (16.7 to 33.3 MHz in 0.05–0.2 GHz range, 66.7 to 133.3 MHz in 0.2–18 GHz ranges) the harmonic number can be estimated quite simply, as follows.

Tune the VFO until either phase-lock or zero beat is obtained, depending on the type of input signal. With the harmonic-number thumbswitches set to 001, read the sampling frequency f_s on the counter. The estimated harmonic number is

$$n = \frac{f_x}{f_s} \qquad (1)$$

where f_x is the approximate input carrier frequency. Now set the estimated harmonic number on the thumbswitches and vary it plus and minus one digit. When the input carrier frequency is known to within the sampling frequency, one of the three counter readings resulting from this operation will obviously be correct.

For cases where the input signal frequency is totally unknown, record the sampling frequency under zero beat or phase-locked conditions. Then either increase or decrease the VFO frequency to zero beat or phase lock on an adjacent harmonic. Again record the sampling frequency. The harmonic number is given by

$$n = \frac{f_{s_1}}{|f_{s_1} - f_{s_2}|} \qquad (2)$$

where f_{s_1} is the sampling frequency corresponding to the first zero beat or phase lock and f_{s_2} is the second sampling frequency observed. The harmonic number calculated by equation 2 corresponds to the second oscillator setting. Thus setting the thumbswitches to n results in a direct counter reading of the input carrier frequency.

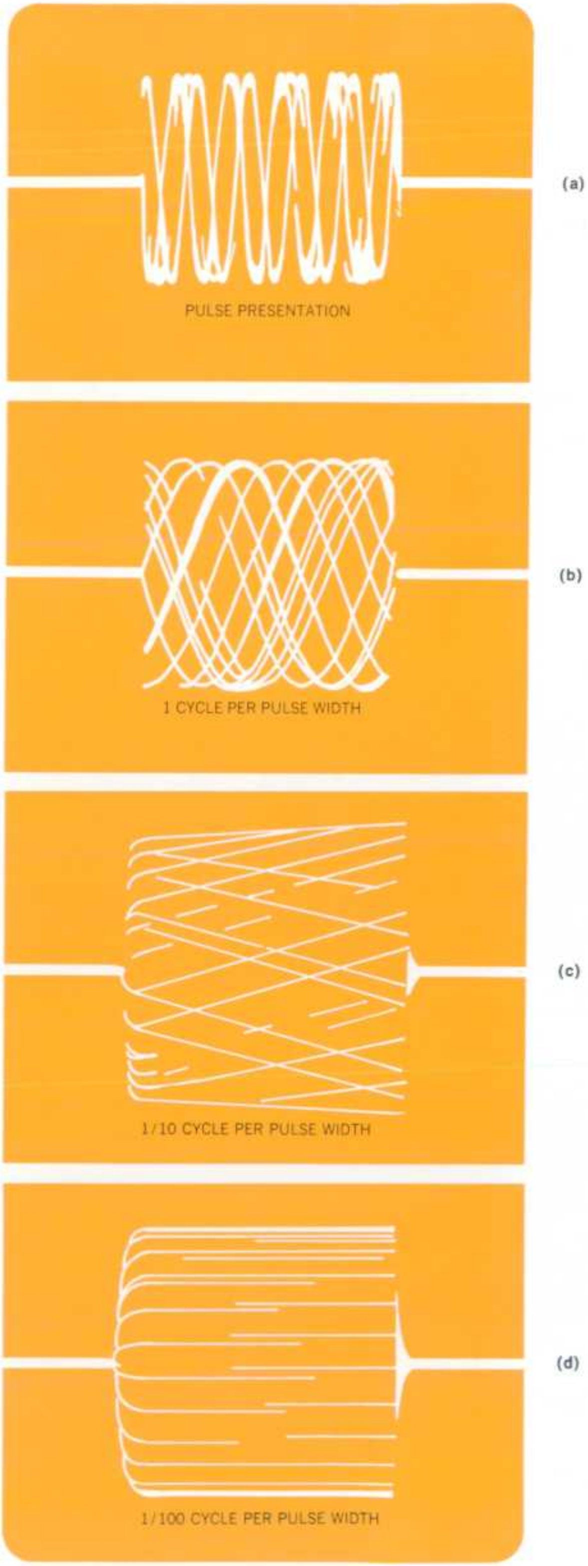


Fig. 6. *Typical waveforms at sampler output while tuning for zero beat (oscilloscope not synchronized to RF carrier). Stability of VFO of new transfer oscillator is high enough to permit tuning within 1/100 cycle per pulse width of zero beat, i.e. within (100 × pulse width)$^{-1}$ Hz. See Fig. 7.*

It is quite simple to check the harmonic number set on the thumbswitches. Observe the counter reading and then either increase or decrease the VFO frequency to an adjacent zero beat or phase lock. Decrease or increase the harmonic-number thumbswitch setting by one unit accordingly and the counter reading should be the same as the first reading. This check is absolute proof of correct harmonic-number determination.

The harmonic-number thumbswitches control circuits which digitally extend the counter time base, thereby multiplying the sampling frequency by the harmonic number, and giving a direct counter reading of the unknown carrier frequency.

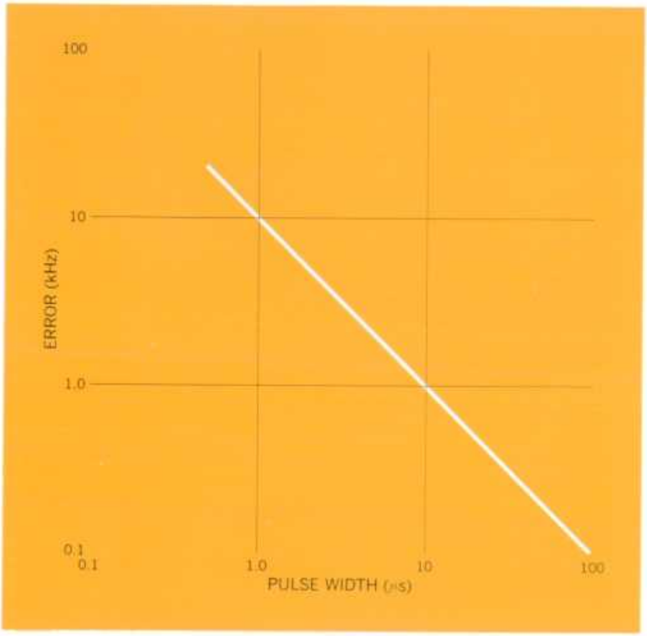


Fig. 7. *Approximate error in measurements of pulsed RF carrier frequencies with transfer oscillator. Estimated error is based on tuning within 1/100 cycle per pulse width of zero beat. Curve is a plot of (100 × pulse width)$^{-1}$ versus pulse width.*

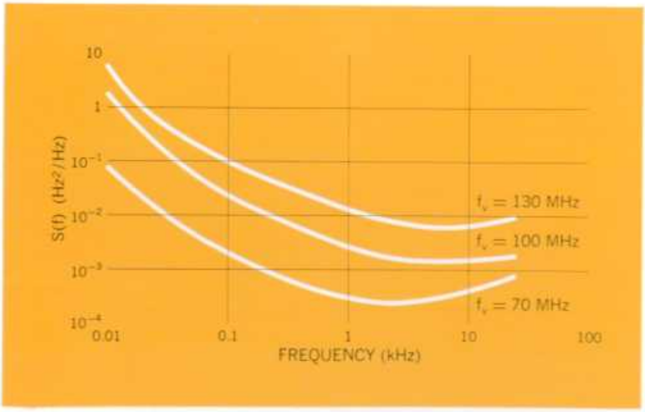


Fig. 8. *Frequency spectral density of VFO of Model 5257A Transfer Oscillator. Short-term rms frequency fluctuations are only about 1 part in 10^7.*

Pulsed RF Signals

To measure the carrier frequency of a pulsed RF signal, the front-panel MODE switch should be turned to PULSED RF. In this mode, the sampler is used for down-converting the input signal.

Fig. 5 shows a pulsed RF signal, its frequency spectrum, and the spectrum of the sampler output signal assuming the sampling is done with an infinite impulse train. In the spectrum of the sampled signal, the line spectrum of the pulsed RF signal is faithfully reproduced at every harmonic of the sampling frequency f_s, including the harmonic centered at dc (see references 1, 2, and 3).

For measuring the carrier frequency f_x, the time waveform corresponding to the spectrum centered at $f \approx 0$ is recovered by low-pass filtering. Fig. 6(a) shows a typical down-converted pulse, with the sampling frequency f_s slightly different from f_x/n. As f_s gets closer to f_x/n, the waveform changes to that of Figs. 6(b), 6(c), and 6(d).

Zero beat ($f_s = f_x/n$) can be determined accurately by tuning the front-panel meter for a maximum reading. As Fig. 3 shows, the amplified down-converted pulses are applied to a peak-holding circuit whose output is displayed on the meter. This circuit has a maximum output under zero-beat conditions.

Generally, zero beats can be determined within 1/100 of a cycle per pulse width, which corresponds to Fig. 6(d). Hence the approximate frequency-measurement error is about one cycle per 100 pulse widths.

Error as a function of pulse width is plotted in Fig. 7. For a 1-μs pulse width, for example, carrier frequencies can be determined within ±10 kHz or one cycle per 100 μs. With a 1-μs pulse width, a 10-GHz carrier can be measured accurately within one part in 10^6.

FM Measurements

Frequency modulation on RF carriers can be measured by using the transfer-oscillator's sampler to down-convert the input signal and an FM discriminator to recover the modulating signal. In this case, the VFO of the transfer oscillator is adjusted for a difference frequency $f_x - nf_s$ of about 1 MHz (f_x is the carrier frequency). Maximum limitations on frequency deviation and modulation rate are functions of the difference frequency selected, as explained in reference 4. When these limitations are not exceeded, the input FM signal is reproduced at the down-converted carrier frequency. The modulation can be recovered by connecting an FM discriminator such as the HP 5210A to the transfer oscillator's PULSED RF OUT BNC connector. The discriminator can be followed by a wave analyzer for spectral analysis.

The minimum peak deviation that can be measured by this method is governed by internal VFO noise. The VFO used in the new transfer oscillator has rms frequency fluctuations of 5 to 20 Hz, measured with an instrument having a 20-kHz bandwidth; this corresponds to short-term frequency stability within about one part in 10^7.

The VFO's mean-square frequency deviations are distributed in frequency as shown by its spectral density S(f), Fig. 8. As a result of these deviations, the signal appearing at the PULSED RF OUT terminal is frequency modulated. At a given modulation rate f, the rms frequency deviation of this signal is

$$\Delta f_{rms}(f) = n[B_{eq}\, S(f)]^{1/2}$$

where B_{eq} is the equivalent noise power bandwidth of the measuring instrument (e.g. a wave analyzer) and n is harmonic number. In deriving this equation, it was assumed that B_{eq} is very narrow, so that S(f) is approximately constant over the measurement bandwidth.

Glenn B. DeBella

Glenn DeBella received his B.S. and M.S. degrees in electrical engineering from San Jose State College in 1962 and 1964. He has also done additional postgraduate work at the same institution. His background includes two years as a U. S. Army radio and radar technician, and three years as a circuit designer for magnetic tape-recording equipment.

Glenn came to HP in 1965. He participated in the development of the 5260A Frequency Divider, and was project leader for the development of the 5257A Transfer Oscillator. He is now an engineering group leader in the Frequency and Time Laboratory.

Glenn is a member of IEEE and Phi Kappa Phi. His article in this issue is the third technical article he has published.

Acknowledgments

It is with great pleasure and appreciation that I acknowledge the group that designed the HP 5257A Transfer Oscillator. My associate in the electrical design was Rolf B. Hofstad. Lawrence A. Lim was responsible for the mechanical design and packaging. James D. Nivison provided outstanding assistance as technician on the project.

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SPECIFICATIONS*

HP Model 5257A
Transfer Oscillator

FREQUENCY RANGE: 50 MHz to 18 GHz.

INPUT SIGNAL CAPABILITY:
CW Signals.
Pulsed RF signals.
Signals with high FM content.

CW MEASUREMENT ACCURACY: Retains counter accuracy.

INPUT SENSITIVITY:
100 mV rms (−7 dBm) for input frequencies of 50 MHz to 15 GHz.
140 mV rms (−4 dBm) for input frequencies of 15 to 18 GHz and VFO FREQUENCY of 125-133.3 MHz.

INPUT IMPEDANCE: 50 Ω nominal.

MAXIMUM INPUT: +10 dBm for CW signals.
2 volts p-p for pulsed RF signals.

APC LOCK RANGE: Approximately ±0.2% of input frequency.

METER:
APC MODE: Indicates loop phase error under locked conditions.
PULSED RF MODE: Zero beat indicator.

PULSED RF OUT: For external oscilloscope, 0.5 volt p-p.

PULSED CARRIER FREQUENCY MEASUREMENTS:
MINIMUM PULSE WIDTH: 0.5 μs.
MINIMUM REPETITION RATE: 10 pulses per second.
ACCURACY: Measurements are accurate within about ±0.01 cycle per pulse width (error ±20 kHz or less).

VFO:
FREQUENCY RANGE: 66.7 to 133.3 MHz.
DRIFT: (With constant temperature in operational range of 0° to 55°C) typically ±2 parts in 10^5 per minute immediately after turn on. Typically ±1 part in 10^7 per minute after 2 hours of operation.
TEMPERATURE VARIATION: Typically 1 part in 10^4 per degree C.

INPUT CONNECTOR: Precision Type N female. Precision Type APC-7 optional.

PRICE: $1850.00.

HP Model 5256A
Frequency Converter

RANGE: As a converter for HP 50 MHz plug-in electronic counters, 8 to 18 GHz using mixing frequencies of 8 to 18 GHz in 200 MHz steps. As a prescaler, 1 MHz to 200 MHz.

ACCURACY: Retains counter accuracy.

INPUT SENSITIVITY: 100 mV rms (−7 dBm) as a converter, 5 mV rms as a prescaler.

INPUT IMPEDANCE: 50 Ω nominal.

MAXIMUM INPUT: +10 dBm; 0 dBm on AUX IN.

LEVEL INDICATOR: Meter aids frequency selection; indicates usable signal level.

AUXILIARY OUTPUT: 1 MHz to 200 MHz difference signal from video amplifier.

REGISTRATION: Counter display in MHz is added to converter dial reading.

INSTALLATION: Plugs into front panel plug-in compartment of HP 50 MHz plug-in electronic counter.

INPUT CONNECTOR: Precision Type APC-7 connector.

WEIGHT†: Net, 8¼ lbs. (3,8 kg). Shipping, 12 lbs. (5,5 kg).

PRICE: $1750.00.

** When used with Hewlett-Packard Electronic Counters: Model 5245L serial prefixed 402 and above, Model 5246L, Model 5245M, and Model 5247M.*

MANUFACTURING DIVISION: HP FREQUENCY and TIME
DIVISION
1501 Page Mill Road
Palo Alto, California 94304

Atomic Second Adopted by International Conference

The 'atomic second' was permanently adopted recently as the International Unit of time by the 13th General Conference on Weights and Measures at its meeting in Paris. This time unit had been adopted on a tentative basis in 1964 but on October 13, 1967 was permanently adopted as one of the International System units.

The atomic second is defined as the duration of 9,192,631,770 periods of the radiation corresponding to the transition between two specific hyperfine levels of the fundamental state of the atom of cesium 133. The Conference abrogated existing definitions which based the International Unit second on the earth's motion.

The new second is, however, chosen to be identical with the 'ephemeris second' which is important to astronomers. Hence, no changes need be made in data given in units of the old standard. The major advantage of the new standard second is that it is accurately and immediately obtainable from commercially available cesium atomic standards. By contrast, several years are required to establish the ephemeris second.

The Conference, in other actions, dropped the name 'micron' and its symbol 'μ,' restricting 'μ' to mean 'micro' (10^{-6}). The former linear measure micron is now to be known as μm (micrometer). The unit of temperature and temperature interval was changed from 'degrees Kelvin' to simply 'kelvin' (symbol: K).

The Conference also added these to the derived units of the International System of Units*:

Quantity	Derived Unit	Symbol
Wave number	1 per meter	m^{-1}
Entropy	joule per kelvin	J/K
Specific Heat	joule per kilogram kelvin	J/kgK
Thermal conductivity	watt per meter kelvin	W/mK
Radiant intensity	watt per steradian	W/sr
Activity (of a radioactive source)	1 per second	s^{-1}

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* *See "International System of Units," Hewlett-Packard Journal, Vol. 15, No. 7, March, 1964, reprinted also in Vol. 18, No. 10, June, 1967.*

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