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The Transistorized RC Oscillator

The illustration below shows the well-known RC test oscillator in a transistorized version which has been designed to provide a test oscillator of very high portability. Physically, the new oscillator is small enough and light enough to be held easily in one hand. Electrically, it operates over the frequency range from 5 cps to 500 kc in 5 ranges. It provides up to 2.5 volts across loads of 600 ohms or more and is in every sense a quality oscillator, having less than 1% distortion, better than 3% frequency accuracy, a constant output with frequency, and outstanding frequency stability. Even warm-up drift is in general negligible. Also the instrument has been designed in a battery operated version so that line-voltage effects are avoided completely as is hum, although in the ac-operated version these factors have been kept very small, too. In addition, since the circuit is fully transistorized, the new oscillator is virtually insensitive to vibration and shock, making it a very stable and rugged precision instrument indeed.

SEE ALSO
"New high-power TWT amplifiers," p. 4

TRANSISTORIZED CIRCUITRY

From a design viewpoint the transistorization of the RC oscillator is interesting because it has resulted in several variations over previous designs. The basic arrangement of the new circuit is shown in Fig. 3. The frequency-

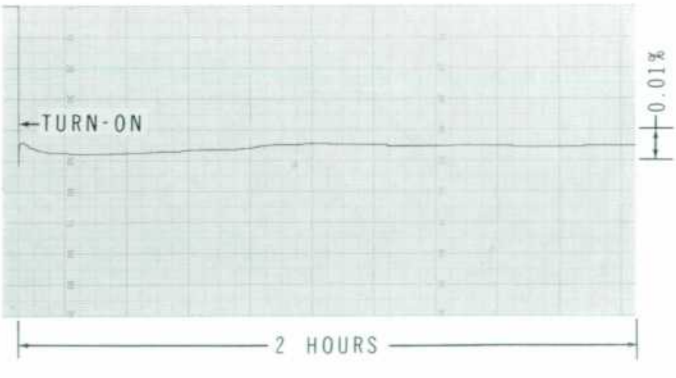


Fig. 2. *Typical frequency-stability characteristic of Model 204B Oscillator. Frequency drift was only about 1 part in 20,000 in complete test including turn-on drift. Instrument begins to operate almost immediately after turn-on.*

Fig. 1 (at left). *New -hp- Model 204B Oscillator is transistorized version of the RC oscillator and operates over the range from 5 cps to 500 kc. The instrument can be battery-operated as shown here but has also been designed in ac-operated version.*

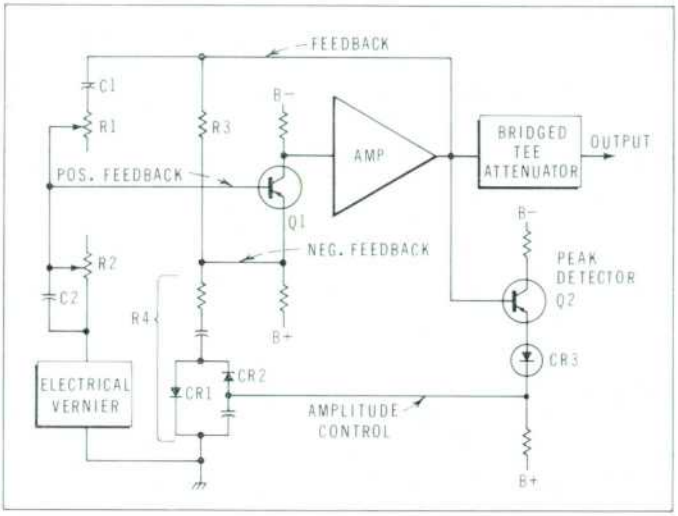


Fig. 3. *Basic circuit arrangement of new RC oscillator. For power economy new amplitude control circuit replaces traditional ballast lamp, but frequency response is very constant as shown in Fig. 5.*

selective positive feedback arms of the RC bridge are formed by C_1, R_1, C_2, and R_2. The negative-feedback arms are formed by R_3 and net work R_4. The main frequency-tuning elements are variable resistances R_1 and R_2, while capacitors C_1 and C_2 are changed to establish the various ranges. The output from the center nodes of the bridge is applied to transistor Q_1 and amplified. The amplifier output then drives both the bridge and the output circuitry. The output amplitude is adjusted by a bridged-T attenuator which has a characteristic impedance of 600 ohms and at least 40 db of control.

The amplitude of oscillations is controlled by the peak detector Q_2 operating with the breakdown zener diode CR_3. The diode establishes a reference voltage with which the amplitude of oscillation is compared. The error voltage is then fed back to control the resistance of the forward-biased diodes CR_1 and CR_2. These in turn affect the total resistance of R_4 in such a way as to maintain the proper amplitude of oscillations.

The tuning resistances are driven through a drive system that gives the customary logarithmic-characteristic frequency dial. An electrical vernier control is provided which has a minimum range of .15% and, besides being convenient for fine tuning purposes, insures infinite frequency resolution despite any slight granularity of the main tuning resistors. The design of the vernier is such that its use does not alter the output signal voltage level.

CONSTANT AMPLITUDE OUTPUT

One design aspect that is readily noticed when using the new oscillator is the effectiveness of the new amplitude control circuit. A new type of control circuit was required since the power drawn by the lamp or ballast element usually used was too great for long battery life. Consequently, the peak detector control circuit shown in Fig. 3 was devised. This circuit evolved with many desirable features. It operates on low signal level and supply power so that long battery life is achieved. It is thermally self-compensating and is extremely rugged so that the amplitude of oscillation is not sensitive to mechanical vibrations or thermal changes.

Of considerable importance for most use, however, is the fact that the amplitude control circuit is extremely sensitive to variations in oscillation level. Since the control circuit compares the oscillation amplitude with a fixed reference voltage and since the envelope loop gain is high, an exceedingly flat frequency response results. This is indicated by the typical frequency response curves shown in Fig. 5. The instrument is rated to have less than 3% amplitude variation over the full 5 cps to 500 kc range, but typical performance is considerably better.

FREQUENCY STABILITY

Despite the fact that the new oscillator is small and portable, there is no reduction in the stability of its signal. This is true because the frequency characteristics of the instrument are virtually independent of normal amplifier variations and primarily dependent on only the components in the resistance-capacitance bridge. For these components, stabilized quality resistances and capacities have been used to achieve an overall temperature coefficient that is rated as being less than $\pm 0.03\%/^\circ C$. Typically, the temperature dependence of frequency will be even less. The use of stabilized bridge components also gives the oscillator ex-

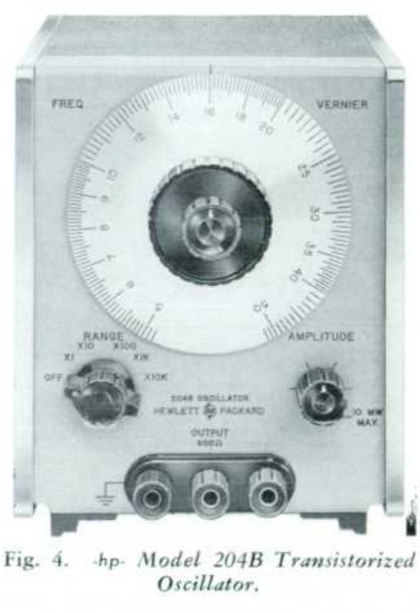


Fig. 4. -hp- *Model 204B Transistorized Oscillator.*

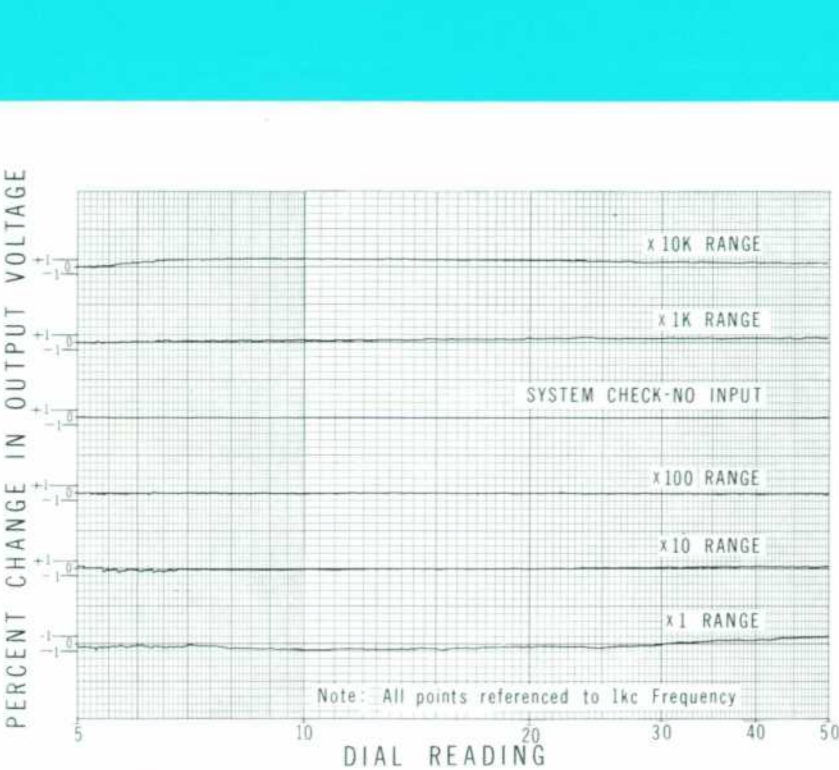


Fig. 5. *Effectiveness of amplitude control circuit as shown by typical frequency response characteristic of Model 204B. Each minor vertical division has value of 1% so overall response is within about ±1%.*

cellent repeatability and long-term frequency stability.

A curve which has practical meaning in the usual day-to-day use of a test oscillator is shown in Fig. 2 (front page). This curve is a two-hour recording of the frequency stability of one of the new oscillators made under usual room conditions. The curve includes the initial turn-on of the oscillator and is thus indicative of actual available stability in a typical case. Note that each major division on the vertical scale represents but 0.01% change in frequency or 1 cps at 10 kc. The overall drift measured in this case is within 0.005%.

OUTPUT CIRCUIT

The output circuit in the oscillator has several points of special interest associated with its design.

The output system is fully floating so that it can be used easily with off-ground loads such as transistor circuits. Using the battery-operated version of the instrument also means that the signal will be hum-free. In the ac-powered version, however, hum and noise are still small, being rated at less than 0.05%.

Output voltage is adjusted by an attenuator located at the amplifier output to maintain signal quality at low levels. The attenuator used is an uncalibrated bridged-T attenuator with a minimum range of 40 db. The instrument has a 600-ohm internal impedance to match common load impedances and is rated for operation into loads of 600 or more ohms. However, the instrument can be operated into lower-impedance loads without substantial loss of performance except for output voltage and battery life.

BATTERY-AC OPERATION

While the oscillator has been basically designed for battery operation, it is also available for ac operation as an optional arrangement. In addition, the ac-operated power supply circuitry for the instrument is available as an assembly so that a battery-operated unit can be field-converted to an ac-operated unit if desired. The ac supply assembly is arranged so that it fits into the battery compartment.

To make the instrument well-suited to battery operation, much attention was paid to achieving high efficiency and low power consumption. The output stage is designed as a class B complementary pair so that battery drain is conserved if less than full signal power is drawn from the instrument. These and other considerations have resulted in a battery life under the condition of maximum battery drain of at least 300 hours. Under conditions of low power output battery life may be increased to 400 hours. Battery replacement is indicated by lack of the ability of the instrument to produce its rated maximum output of 2.5 volts across a 600-ohm external load. A pilot "light" is included in the instrument but is of the mechanical type and requires no battery or ac power.

ACKNOWLEDGMENT

The author is grateful for the suggestions and ideas of Brunton Bauer, Bernard M. Oliver and others who contributed to the successful completion of the instrument, and to Richard B. Osgood who performed the mechanical design.

—David S. Cochran

SPECIFICATIONS
-hp-
MODEL 204B
5 CPS-500 KC OSCILLATOR

Frequency range: 5 cps to 500 kc in 5 ranges. Vernier provided.
Dial accuracy: ±3%.
Frequency response: ±3% into rated load.
Output: 10 milliwatts (2.5v rms) into 600 ohms; 5v rms open circuit. Completely floating.
Output impedance: 600 ohms.
Output control: continuously variable bridged "T" attenuator with 40 db minimum range.
Distortion: less than 1%.
Hum and noise: less than 0.05%.
Power source: 4 battery cells at 6.75 volts each, 7 ma, 300 hours. AC power pack optional.
Dimensions: 6 3/32 in. high, 5 1/8 in. wide, 8 in. deep.
Weight: 6 lbs.
Price: -hp- Model 204B Oscillator, $275.00.
Options: 1. AC power pack installed, add $25.00.
Field battery-to-AC Conversion Assembly, -hp- No. 204B-95: $45.00.

Prices f.o.b. factory
Data subject to change without notice.

NEW ONE WATT TWT AMPLIFIERS FOR MORE RAPID MICROWAVE MEASUREMENTS

Fig. 1. *New twt amplifier (center) increases signal generator levels to 1 watt in 1-12 gc range. With sweep-frequency generators internal modulation system can be used to provide constant power with frequency at levels up to 1 watt.*

Several years ago the Hewlett-Packard laboratories developed a group of high-gain broadband microwave amplifiers employing traveling-wave tubes [1, 2]. Besides the flexibility and convenience these amplifiers afforded for microwave work, they were also noteworthy in that they constituted the first practical wide-band application of the traveling-wave tube.

Now, these amplifiers have been supplemented by four new twt amplifiers that collectively cover the frequency range from 1 gc (kmc) to 12.4 gc and individually produce a full watt of rf power output. This output level can be obtained from an input of 1 milliwatt or less, since the gain of the amplifiers is at least 30 db.

The amplifiers have the further new provision of a self-contained modulation amplifier which enables them to be amplitude-modulated by common types of signals down to and including dc. Thus, the amplifiers can be used not only as power amplifiers to form high-power signal sources from single-frequency signal generators but also as power levelers to form constant-highpower type swept-frequency sources when used with swept-frequency generators. For wide-band testing of microwave devices, this is a very great convenience.

The new amplifier units incorporate periodic permanent-magnet focused twt's and high-performance power supplies and are housed in the new -*hp*- cabinets. The result is amplifier units that are attractive, light in weight, simple to operate, readily usable on a bench or in a rack, and that have excellent gain stability under various operating conditions and environments.

ELECTRICAL ARRANGEMENT

The electrical arrangement of the amplifier units is shown in Fig. 2. The power supply provides regulated voltages for the twt heater and for all of the electrodes except the control/focus grid. The voltage for this grid is derived from a regulated supply but is dually controlled by

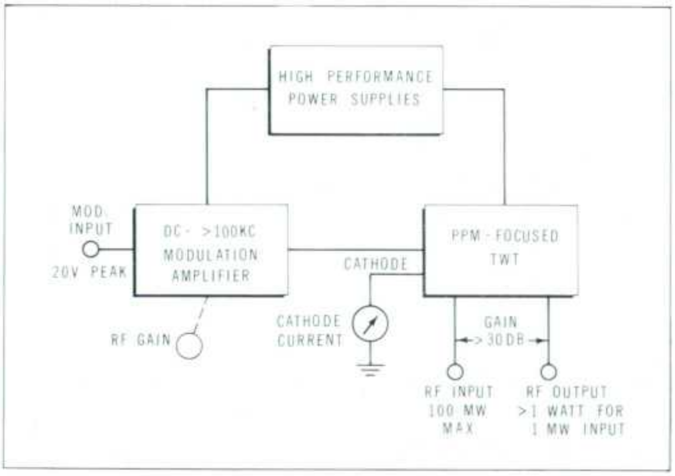


Fig. 2. *Basic circuit arrangement of new amplifier units. Twt's are of periodic permanent-magnet-focused type.*

[1] P. P. Lacy and D. E. Wheeler, "New Broadband Microwave Power Amplifiers Using Helix-Coupled TWT's," *Hewlett-Packard Journal*, Vol. 6, No. 3-4, Nov.-Dec., 1954.

[2] Peter D. Lacy and Geo. W. C. Mathers, "New TWT Amplifiers with Provision for Simulating Special Microwave Signals," *Hewlett-Packard Journal*, Vol. 7, No. 5, January, 1956.

Model 489A
1-2 gc

Model 491C
2-4 gc

Fig. 3. *New series of*

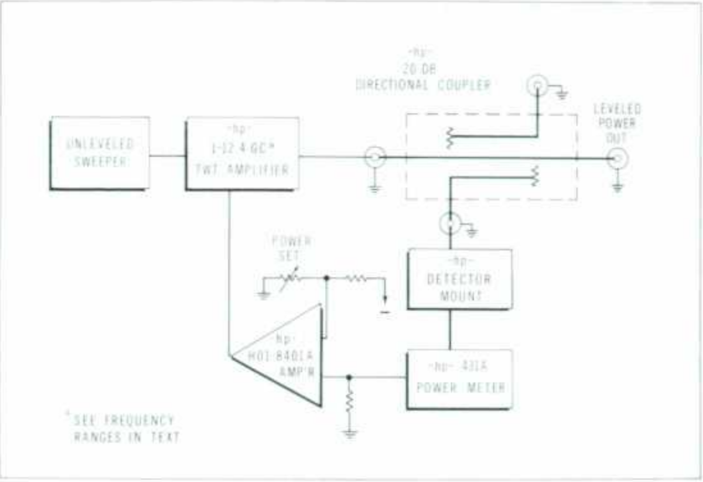


Fig. 4. *Equipment arrangement for forming constant-power 1-watt sweeper using new amplifiers with unleveled, low-power sweep generator.*

the signal applied to the *Mod. Input* terminal and by the setting of the front panel rf *Gain* control. This dual arrangement is thus a means of modulating and/or controlling the microwave power output or the twt gain. The *Gain* control can be adjusted to set the average rf output level so that normal modulation, up-modulation or down-modulation can be used, depending on the polarity of the available input signal. The polarity of the modulation amplifier is such that a positive input signal produces increased rf output.

The modulation amplifier is direct-coupled and has a small-signal bandwidth ($\cong$1 volt p-p input signal) of 500 kc independent of the average rf power output or a dc modulation input voltage. The large-signal bandwidth ($\cong$20 volts p-p input signal) is more than 100 kc, permitting modulation ($>$20 db on-off ratio) by sine wave and by square waves and pulses where a 5- to 10-microsecond-rise time is sufficient. The twt itself is protected from too large a positive input signal by a clamping diode on the control grid and by helix current overload relay.

Besides the *Gain* control the only operating control on the amplifiers is the power switch. In these units the switch is arranged with a stand-by position which can be used to obtain a 90 db on-off ratio of the rf output when it is desired to check the zero output condition of a system without disturbing the source of the rf power being amplified.

POWER LEVELING

In microwave test work it is often valuable to have a wide-band frequency source that has a constant, high power output. Such a source, for example, permits fast testing of broadband devices by means of the single-coupler reflectometer method[3]. For such work the new amplifiers are a valuable means of leveling the output power of signal sources whose power is subject to large excursions. A method for accomplishing this with a typical signal source is shown in Fig. 4. The degree to which the arrangement will level the output of a signal source is indicated by the "before and after" curves in Fig. 5. The leveled curve is constant except for the variation of approximately 1 db introduced by the characteristic of the directional coupler used.

The arrangement indicated in Fig. 4 permits leveled sources to be obtained at one watt output from 1 to 12.4 gc.

REMOTE PROGRAMMING

Where remote programming of an rf source is required, it can be achieved by using the modulation capabilities of the new amplifiers. Since the modulation amplifier is dc-coupled, remote programming is easily accomplished.

GENERAL

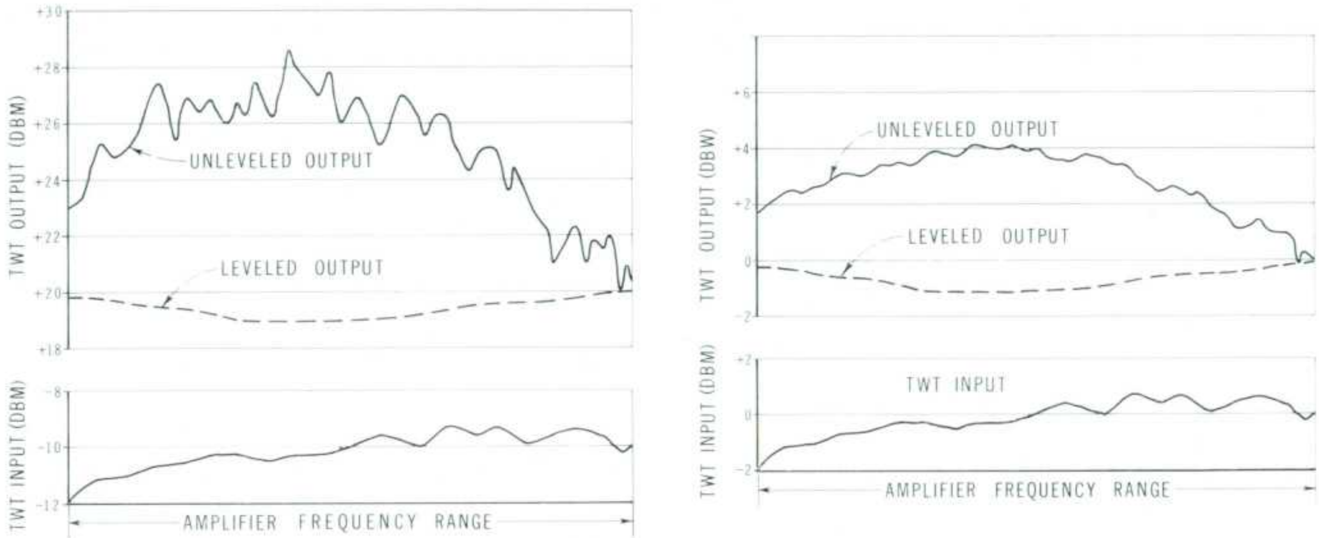
The high voltage power supplies in the amplifiers are relatively simple but have been carefully designed and checked for high stability with varying line voltage and temperature. For example, the 2500-volt helix supply in the two higher frequency amplifiers typically has less than 5 mv of ripple and less than 5 volts change in dc voltage for a line voltage change of $\pm$15% or an ambient temperature change of 50°C. In addition, the twt filaments are operated from a regulated dc voltage to give improved stability and minimal residual amplitude modulation. These measures result in a residual amplitude modulation that is more than 50 db below the rf

[3] J. K. Hunton and Elmer Lorence, "Improved Sweep Frequency Techniques for Broadband Microwave Testing," *Hewlett-Packard Journal*, Vol. 12, No. 4, December, 1960.

Model 493A
4-8 gc

Model 495A
7-12.4 gc

-hp- Microwave Amplifiers.



(a)

Typical unleveled and leveled power output using new twt amplifier as indicated in Fig. 4. Slight variation in leveled curve is response of directional coupler in Fig. 4.

(b)

Curves similar to those in (a) except as obtained with 1-milliwatt input.

Fig. 5. *Comparison of power output curves using new amplifiers at two input levels and in unleveled and leveled applications.*

output and a residual phase modulation that is less than 1°. Also, the rf gain variation for a ±10% line voltage change is less than ±0.5 db and the corresponding change in rf phase shift in the amplifier is less than 40°.

ACKNOWLEDGMENT

The author wishes to acknowledge the effort particularly of Fred H. Meyers and George C. Stanley, Jr. toward the design and construction of these amplifiers.

—George W. C. Mathers

SPECIFICATIONS
-hp-
MODELS 489A, 491C, 493A, 495A
MICROWAVE AMPLIFIERS

Frequency Range:
Model 489A: 1 to 2 gc
Model 491C: 2 to 4 gc
Model 493A: 4 to 8 gc
Model 495A: 7 to 12.4 gc

Output for 1 mw input: at least 1 watt.
Maximum rf input: 100 mw.
Small signal gain: greater than 30 db.
Input, output impedance: 50 ohms, swr less than 3.1.
Connectors: type N, female.
AM passband: dc to 100 kc.
Modulation sensitivity: approximately 20 db change in rf output for a 20-volt peak modulating signal.
Front panel control: Gain; varies grid voltage.
Meter monitors: cathode current.
Dimensions: cabinet mount; 16¾ in. wide, 5½ in. high, 18⅜ in. deep.
Rack mount: 19 in. wide, 5¼ in. high, 16⅛ in. deep behind panel.
Weight: net 40 lbs., shipping 60 lbs.
Power: 115 or 230 volts ±10%, 50 to 60 cps, approximately 225 watts.
Price:
Model 489A: $2300.00
Model 491C: $2300.00
Model 493A: $2900.00
Model 495A: $2900.00
Prices f.o.b. Palo Alto, Calif.
Data subject to change without notice

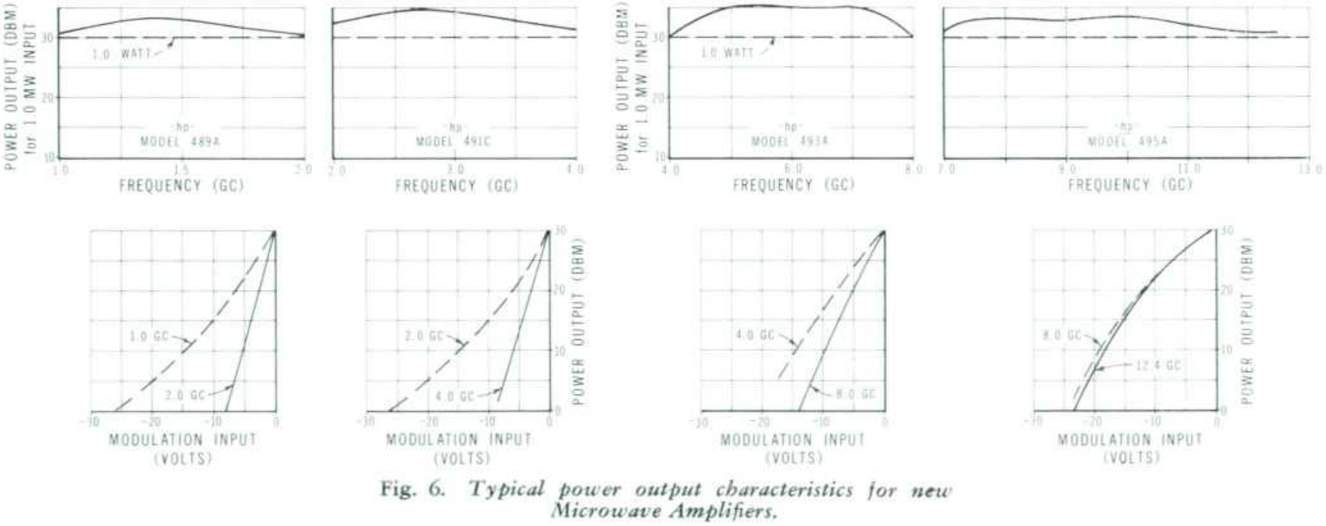


Fig. 6. *Typical power output characteristics for new Microwave Amplifiers.*

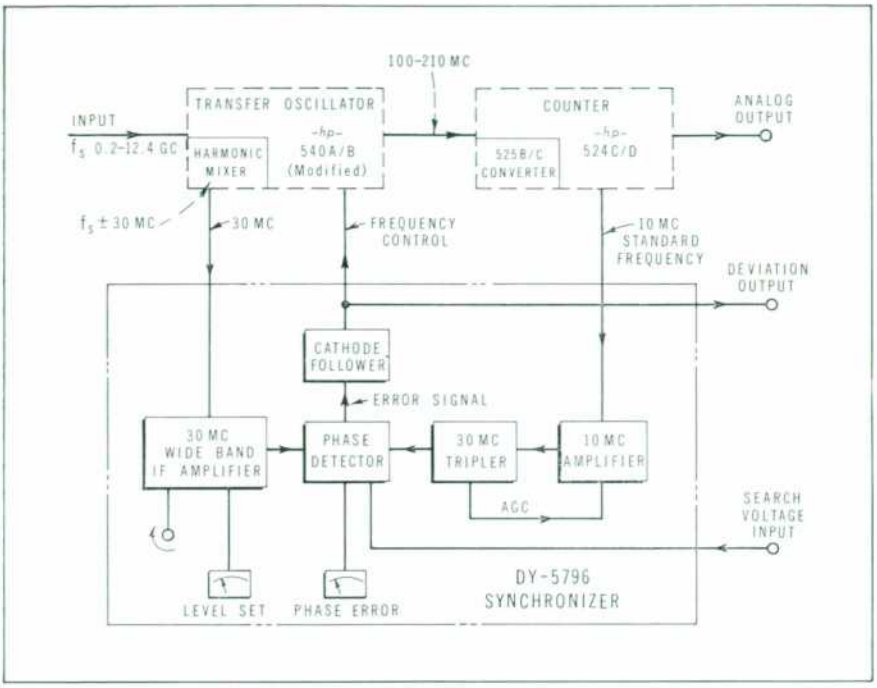


Fig. 6. *Detailed block diagram of Dymec 5796 Synchronizer.*

The 10 mc reference signal from the counter is amplified in a separate channel and tripled in frequency to generate a 30 mc signal reference. A delayed agc loop in this channel maintains a constant reference level into the phase detector. When sufficient i-f signal is also applied (as indicated by the *Level Set* meter) to produce limiter action, the detector sensitivity is constant and independent of signal and reference level variations.

Detector output is indicated on the meter and, after passing through a direct-coupled cathode follower, is available as a frequency control signal for the Transfer Oscillator. The output is a cosine function of phase difference and has a peak value of 7 volts. A dc adjustment of the cathode follower output enables setting the average output level at zero.

DETERMINING HARMONIC NUMBER

Since the transfer oscillator range is from 100 to over 200 mc, the possible number of harmonics that could be used to zero-beat with the signal frequency is at least equal to the signal frequency divided by 200 mc, e.g., at 12 gc/s there are more than 60 harmonics available. The number can be doubled because the Synchronizer can be locked with an oscillator harmonic either 30 mc above or below the signal frequency. This results in pairs of lock-in points separated by 60/N mc on the oscillator dial. *This "pairing" of lock-in points provides an easier means of determining the harmonic in use than is possible without the Synchronizer.* The operator notes the frequency reading on the counter at each of a pair of lock points, and divides their difference into 60 to obtain the harmonic number. The signal frequency is the counter reading multiplied by the harmonic number, plus or minus 30 mc/s depending on whether the upper or lower frequency is used.

TRANSFER OSCILLATOR FREQUENCY CONTROL

A minor modification to the automatic frequency control system of a standard -hp- 540A or 540B Transfer Oscillator provides an increased range of control for use with the DY-5796 Synchronizer. (A modification kit, available from Dymec, includes the necessary components and a new frequency dial that reflects the change in the upper frequency of the transfer oscillator from 220 mc to 210 mc.)

CAPTURE AND LOCK RANGE PARAMETERS

The ±7 volt control voltage from the Synchronizer produces at least ±0.05% change at 100 mc and ±0.2% at 200 mc in a modified Transfer Oscillator. The reduction in control at the low frequency end is due to a swamping effect caused by the higher tuning capacity, and points out the desirability of using the highest possible dial setting to obtain the greatest control range. The control range, expressed as a percentage, also defines the signal frequency lock range; thus, ±0.2% at 12.4 gc corresponds to a 50 mc range. A typical curve of lock range versus dial setting is shown in Fig. 7.

Whenever feedback is employed in a control system, the effect of loop gain and bandwidth variations on stability must be considered by the designer. In this system, the loop gain is a function of the harmonic used, since the i-f frequency is obtained by comparing the signal with an oscillator harmonic. Stable control loop design requires the capture range to be less than the open-loop bandwidth of the system. However, the lock-in range f_1 can be made much greater than the open-loop bandwidth, and is expressed as follows:

$$f_1 = 2K_1 K_2 N$$

where K_1 is the detector sensitivity in volts per radian
K_2 is the oscillator control slope in mc per volt
N is the harmonic number

Typical values are

$K_1 = 7$ volts per radian
$K_2 = 0.1$ mc/s per volt (at 200 mc dial setting)
$N = 60$ (at 12.4 gc)

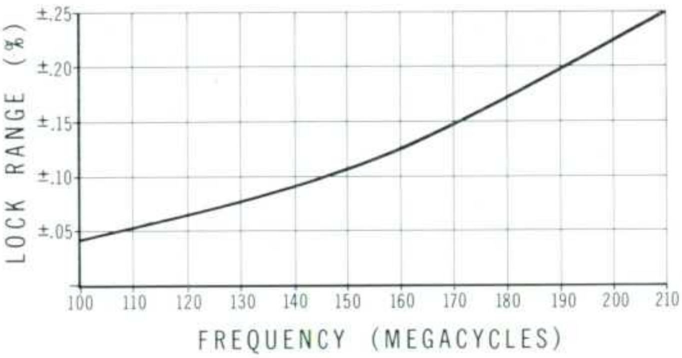


Fig. 7. *Curve of typical lock range of Dymec 5796 Synchronizer in terms of transfer oscillator frequency dial setting. At transfer oscillator harmonics lock range percentage applies to harmonic frequency.*

This results in a maximum lock-in range of about ±40 mc at 12.4 gc. Because of control slope non-linearity and conservative rating practices, a lock-in range of ±25 mc (±0.2%) is guaranteed at 12.4 gc. The capture range is limited to a value less than the system bandwidth, or typically 1 mc.

To capture a signal and obtain synchronization, the Transfer Oscillator must be tuned so that the difference frequency is very close to 30 mc. Normally, it is tuned through the proper point in order to capture the signal and then settled back into the wide lock-in range. The lock-in range is centered by tuning the Transfer Oscillator to indicate center on the Phase Error meter. As the signal drifts, the phase error increases until the edge of the lock-in range is reached — the *Phase Error* meter needle enters the end areas of the scale. Synchronization on a drifting signal can be maintained without measurement interruption by retuning the oscillator to re-center or reverse the *Phase Error* meter indication whenever it nears the edge. Since phase lock is held during these adjustments, no frequency error occurs, and the counter reading is not disturbed.

An interesting example of how a drifting signal can be recorded with a Synchronizer system is the klystron oscillator drift record shown in Fig. 5.

F-M MEASUREMENTS

The amount and nature of incidental f-m in the measured frequency can be obtained from the oscillator control voltage made available at the *Deviation Output* terminals on the front panel. The sensitivity of this measurement is directly related to the slope of the oscillator frequency control circuit. At a dial setting of 200 mc, the slope is about 100 kc per volt. The signal deviation is determined by multiplying the oscillator deviation by the harmonic number. The oscillator control slope can easily be measured by using a variable voltage source and the -*hp*- 524/525 Counter/Converter at various dial settings.

One error source should be considered in applying this technique. The measured f-m is slightly less than the signal f-m, because the control loop gain is finite and a function of oscillator and modulating frequencies as well as harmonic number. The f-m, measured at dial settings around 200 mc, will be within 5% of the signal f-m for modulating frequencies below 7 kc and harmonics above the first. The 5% error limit increases to 50 kc as the harmonic number reaches 60. (This is approximately proportional to the root of the harmonic number.)

The maximum f-m deviation that can be handled without loss of synchronization is obtained when the oscillator is tuned for zero phase error indication, thus centering the f-m in the lock range. In this condition, f-m at rates up to 1000 cps can be measured to the full limits of the lock-in range of ±0.2%. Above 1000 cps, the maximum permissible deviation is reduced by 20 db per decade.

The minimum measurable f-m is limited by the residual f-m of the Transfer Oscillator itself. This is typically 150 cps peak deviation at dial settings around 200 mc, or less than ±.0001%. This occurs principally at a 60 cps rate.

ACKNOWLEDGMENT

The design of the Synchronizer was based on a technique developed by Duane Marshall in the -*hp*- Frequency and Time Engineering Department. The design group at Dymec included John Hasen, who performed the circuit development, and Kenneth G. Wright, who performed the mechanical design.

—Albert Benjaminson

OVERALL SPECIFICATIONS
(Transfer Oscillator plus Counter plus Synchronizer)

Frequency Range: 0.2 to 12.4 gc.
Sensitivity: —10 dbm minimum signal input at 12.4 gc, decreasing to —40 dbm at 200 mc.
Lock-On Range: ±0.2% of signal frequency maximum. (Depends on Transfer Oscillator setting, see Fig. 7 in text.)
Accuracy: ± Stability ± resolution; see following entries.
Stability: $3/10^8$ short term, $5/10^8$ per week. May be used with external frequency standard, e.g. -*hp*- 103AR for $5/10^{10}$ per day.
Resolution: ±1 count at transfer oscillator frequency, equivalent to $5/10^9$ with 1-second counter gate, or $5/10^{10}$ with 10-second gate (at 200 mc oscillator setting).
F-M Measurement: Deviations up to lock-on range at rates to 1 kc. Above 1 kc deviation limit reduced at 20 db/decade to maximum of 0.001% of 200 kc.

SPECIFICATIONS
DYMEC MODEL 5796 SYNCHRONIZER

Input Requirements:
30 mc Input: 150 μv rms minimum (front panel BNC).
10 mc Input: O.8v rms minimum (front panel BNC).
Error Signal Output: ±7v maximum for full lock-on range (rear panel BNC).
Deviation Output: 14v peak-to-peak at modulation rates up to 1 kc. Decreases at 20 db/decade at rates to 200 kc. (Available at front panel binding posts).
Search Voltage Input: Capture point may be varied over desired part of lock range by application of dc to 60 cps signal, ±7v peak maximum. (Rear panel binding posts.)
Power Required: 115/230v ±10%, 50-1000 cps, 35 watts.
Dimensions: 19″ wide, 5½″ high, 9½″ deep.
Weight: 14 lbs. net, 22 lbs. shipping.
Price: DY-5796 Transfer Oscillator Synchronizer (rack mount) $685.00.

All prices f.o.b. Palo Alto, California
Data subject to change without notice

Dymec
395 Page Mill Road
Palo Alto, California