HP AN71

# ADVANCES IN RF MEASUREMENTS USING MODERN SIGNAL GENERATORS 50kc-480Mc

## APPLICATION NOTE SEVENTY-ONE

HEWLETT hp PACKARD

HP AN71

APPLICATION NOTE 71

# ADVANCES IN RF MEASUREMENTS USING MODERN SIGNAL GENERATORS 50KC - 480MC

HEWLETT-PACKARD COMPANY

1501 PAGE MILL ROAD, PALO ALTO, CALIFORNIA, U.S.A.

Printed: JAN 1966

## TABLE OF CONTENTS

# SECTION I
# INTRODUCTION

## BACKGROUND

In many applications, the performance of existing HF to UHF signal generators is becoming marginal. Communications and data links are using closer channel spacings, single-sideband, and sub-carriers to conserve the already crowded frequency spectrum. Phase modulation is being used in deep space missions to obtain better data reception with minimum bandwidths. This activity requires better receiver performance. Designing and testing such receivers demands signal generators with greater frequency stability and settability plus improved modulation characteristics.

FM and phase modulation receivers require signal generators with good frequency stability and low residual FM in order to make valid tests. Thus, it is desirable to include FM and phase modulation capability in a new stable generator.

Another application directly related to receiver performance, is the testing of LC, crystal, and mechanical filters. Such filters are used to obtain higher selectivity in receivers, and restrict transmitter outputs. Testing a filter with 60 db skirts for 1 kc R. F. frequency change is not uncommon and the requirement for a stable and precise generator is clearly evident. Other applications for generators in the 50 kc to 480 Mc region include amplifier testing, driving sources for impedance and attenuation measurements, crystal resonance tests and others.

The hp 606B, 608E/F signal generators and 8708A synchronizer provide new capabilities and improved performance over existing generators to meet greater demands in the HF to UHF bands.

## NEW AND IMPROVED FEATURES

### HP 606B SIGNAL GENERATOR 50 KC - 65 MC

From most outward appearances, the 606B looks much the same as its predecessor, the 606A. Those who are already accustomed to operating the 606A will have no trouble getting acquainted with the 606B. Those who are just meeting the 606-type generator will find the front panel layout logical and straightforward. Look carefully at the photo in Figure 1 and you will note the following new or improved features from left to right on the lower panel:

1. $\Delta$f frequency vernier–
   Provides electrical vernier for frequency tuning resolution of approximately 5 to 10 parts per million. This means tunability, depending on RF frequency, to within 1 cps at 50 kc and 300 cps at 65 Mc.

2. Crystal calibrator - 100 kc or 1 Mc–
   An improved solid state calibrator provides $1/10^4$ frequency accuracy at 100 kc or 1 Mc intervals over the full instrument range.

3. Uncalibrated RF output–
   Here is a high level RF output (approx. 0. 2v) from the oscillator to feed a counter and/or the 8708A synchronizer. It's independent of attenuator setting or any AM being applied to the main RF output so you can continuously monitor frequency on a counter during critical low level tests, or AM.

4. AM modulation–
   A new buffer stage now separates the oscillator and amplifier so when you AM at 30%, incidental FM is less than ($5/10^6$ + 100 cps) peak. This is an improvement of five times over the "A" model.

5. Frequency control input–
   DC voltage of -2v to -32v applied here will swing the oscillator frequency up to 0. 2% at the low ends of each band and 2% at the high ends. Voltage controlled capacitors in the oscillator tank are the secret. This input accepts the control voltage from the 8708A synchronizer for phase locked frequency stability of $2/10^7$/10 minutes, and adds narrow band frequency, or phase modulation capability. When locked, the 606B is free of microphonics too.

6. Frequency analog output–
   This output is a resistance which varies inversely with the generator frequency dial setting. The resistance change with frequency is required by the 8708A to maintain constant loop gain in the phase lock system. Phase locking is automatic at any frequency.

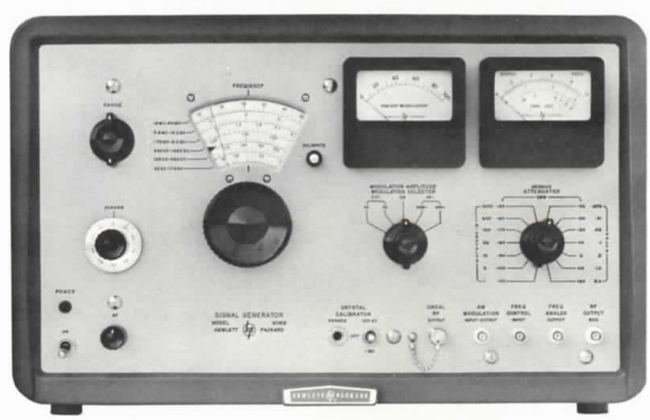


Figure 1. HP 606B Signal Generator provides up to 3 volts of leveled RF from 50 kc to 65 Mc. Improved performance and the ability to be phase locked to the HP 8708A Synchronizer solves problems of drift, microphonics, incidental FM, and tuning resolution for faster, more accurate tests.

7. RF output - 50Ω –
And here we are with some of the best behaved "Hertz's" you'll find this side of a low cost synthesizer – and for a lot less money. The output is leveled, accurate to 1 db, continuously variable from 0.1μv to 3v, and low in AM distortion. When operated with the 8708A, the 606B is free of microphonics and residual FM. It all starts back on the left side of the instrument with the power switch that we almost overlooked; behind it is an all new solid state power supply for greater reliability. See the hp 606B Technical Data sheet for complete specifications.

## 608E SIGNAL GENERATOR 10 Mc - 480 Mc

For less demanding applications where frequency stability of the older 608C/D is sufficient ($5/10^5$) we recommend the 608E. This unit has all the good features of the C and D versions plus several new advantages. It does not contain Varicaps* in the oscillator, as does the 608F described later, and therefore cannot be phase locked or frequency modulated. This way, the user can save money if phase lock is not required, and he still gets improved performance in other areas.

Look at the 608E photo in Figure 2. The difference between the 608E and older 608D front panel is small, but very important to anyone interested in saving hours of test time and improving accuracy.

1. Uncalibrated RF output–
Provides a high level RF output of approximately 0.2v which is independent of attenuator setting or AM applied to the main RF output. This enables frequency monitoring during critical low level tests or while amplitude modulating.

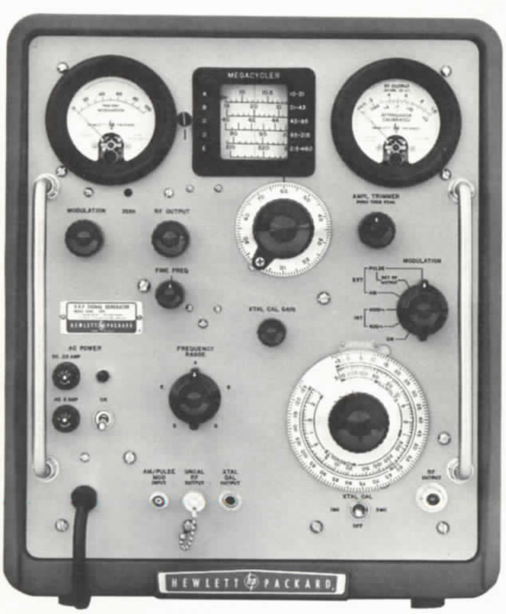



Figure 2. HP 608E Signal Generator provides up to 1 volt RF output from 10 Mc to 480 Mc. New leveling feature saves set up time when changing test frequency by holding output level constant. Other new features and improvements simplify tests and increase accuracy.

*Registered trade mark, TRW Semiconductor, Inc.

2. Amplifier trimmer - push then peak–
The RF output is now leveled across wide bands to retain ±1 db output accuracy without readjusting the AMPL TRIMMER. There is an optimum setting of the trimmer on each band for leveling across band A through D. Band E may require two settings to level the entire band, depending on the particular instrument. Once this setting is made, there is no further need to readjust the trimmer and RF output controls for each frequency change within the band. Now, if you wish to amplitude modulate, you must PUSH and PEAK the AMPLITUDE TRIMMER whenever changing frequency because the oscillator and amplifier must track exactly to avoid assymmetrical AM sidebands. But because of leveling, there is no need to readjust the RF output control for every frequency change. This feature reduces setup time and reduces chance for errors.

3. Crystal calibrator - 1 Mc - 5 Mc–
The crystal calibrator provides frequency check points at 1 Mc and 5 Mc intervals from 10 Mc to 480 Mc accurate to $1/10^4$ giving a 50X improvement in the basic dial accuracy without external frequency meters.

4. 1 Volt RF output - buffered–
Provides a healthy output voltage for receiver AGC tests and other high level requirements, yet contains a buffer stage between the oscillator and power amplifier for low incidental FM.

5. Lower AM distortion - better modulation meter accuracy–
The negative feedback around the power amplifier for leveling reduces AM envelope distortion. Using an hp 200CD to externally AM the 608E, distortion is less than 1% from 20 cps to 20 kc at 30% AM. Using internal 400 cycle or 1 kc AM, distortion is less than 2% at 30% AM. Reduced distortion allows improved modulation meter accuracy to 5% of full scale for 0 - 80% AM, and 10% of full scale for 80 - 95% AM.

Complete specifications for the 608E are contained in the hp 608E/F Technical Data sheet.

## 608F SIGNAL GENERATOR 10 Mc - 455 Mc

The 608F has all the features of the 608E plus the ability to phase lock to the 8708A synchronizer. Varicaps in the 608F oscillator circuit allow voltage controlled frequency over a narrow range which is suitable for phase locking and narrow band FM or phase modulation (PM).

Looking at Figure 3 you will see two new jacks besides the ones mentioned for the 608E. These are:

1. Frequency control input–
DC voltage of -2 to -32v applied here changes the oscillator tank capacity in order to swing frequency. This input accepts the control voltage from the hp 8708A synchronizer for automatic frequency stability of $2/10^7$/10 minutes, or better. When phase locked, 608F microphonics are re-

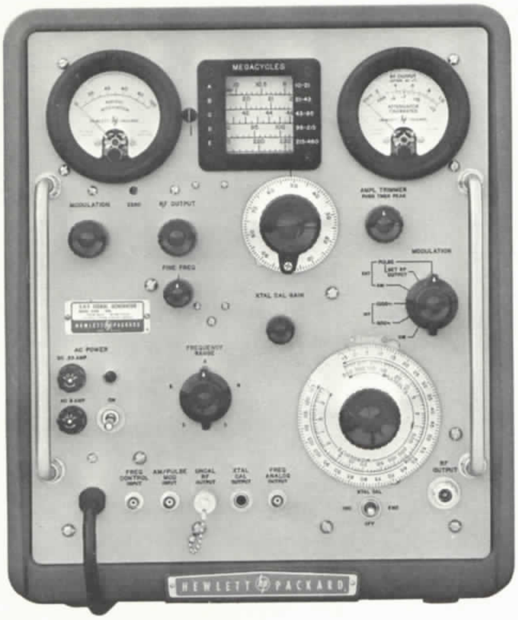


Figure 3. HP 608F Signal Generator provides up to 0.5 volt from 10 Mc to 455 Mc with the ability to be phase locked to the HP 8708A Synchronizer. Drastic reduction of drift and microphonics with phase lock eliminates a large source of error when testing high slope or narrow-band circuits. Linear FM and PM is also possible when phase locked, opening new areas of application.

moved and residual FM drastically reduced. This input is also useful for frequency or phase modulation of the 608F, either through the synchronizer or directly.

2. Frequency analog output–
A resistance inversely proportional to the frequency dial setting is fed out to the 8708A synchronizer to maintain constant loop gain in the phase lock system regardless of frequency. This is required because a given voltage change on the varicaps represents a greater frequency change at high frequencies.

Because of the varicaps in the 608F oscillator, circuit Q is slightly lower than in the 608E. For this reason, maximum RF output is specified at 0.5 volts, although the instrument is capable of 1 volt over most of the range. One other difference between the 608E and F is the reduction in upper frequency range from 480 Mc to 455 Mc. This reduction occurs because of the small residual capacitance added to the oscillator circuit by the varicaps.

All the other features described for the "E" such as leveled output, uncalibrated output, improved AM specs, and low incidental FM are included in the F. Specifications for the 608F are included in the 608E/F Technical Data sheet.

## 8708A SYNCHRONIZER - 50 kc TO 500 Mc

The hp 8708A synchronizer operates on a sampling-phase lock technique with the 606B or 608F to provide a stable reference signal and frequency control voltage. The synchronizer can also be used with an external audio oscillator for FM or phase modulation of the 606B or 608F. The 8708A differs from conventional "AFC" or phase comparator systems in two important ways:

1. Phase lock with either the 606B or 608F is completely automatic - no searching, peaking or manual locking is required. When the 8708A is connected to either generator, the system is frequency stable to $2/10^7/10$ minutes or better - automatically! Unlike an AFC system, the 8708A does not require an actual frequency change before an error signal is developed so frequency is held constant.

2. Locked frequency is continuously variable over the complete 606B and 608F range. The generator's main tuning control coarse tunes frequency in steps across the band. The 8708A frequency tuning control provides continuous resolution between steps, of $2/10^7$ for exact settability - not just discrete points.

Other important features of the 8708A include:

3. Frequency or phase modulation with better than 1% linearity (see graphs in Figures 5, 6, and 7 for deviations, rates and linearity).

4. Reduction of incidental FM when amplitude modulating the 606B or 608F.

5. Will accept an external frequency standard (20 Mc) for even greater stability than the $2/10^7$ internal reference. The phase locked 606B or 608F will then have the stability of the external standard. In this mode, the system will lock only at discrete frequencies across the band rather than having continuous tuning control (unless the external standard frequency is continuously over a ±50 kc range.) One technique for achieving higher stability with essentially continuous tuning would be to use a Frequency Synthesizer such as the hp 5100/5110A. The hp 5103A 10 Mc synthesizer can also be used with a 10515A doubler for a lower cost external reference.

Specifications of the 8708A are given in the Technical Data Sheet.

Figure 4. HP 8708A Synchronizer phase locks either HP 606B or 608F, giving dual range versatility in a single compact unit. Unique system provides automatic phase lock and continuous tunability for simple and flexible use.

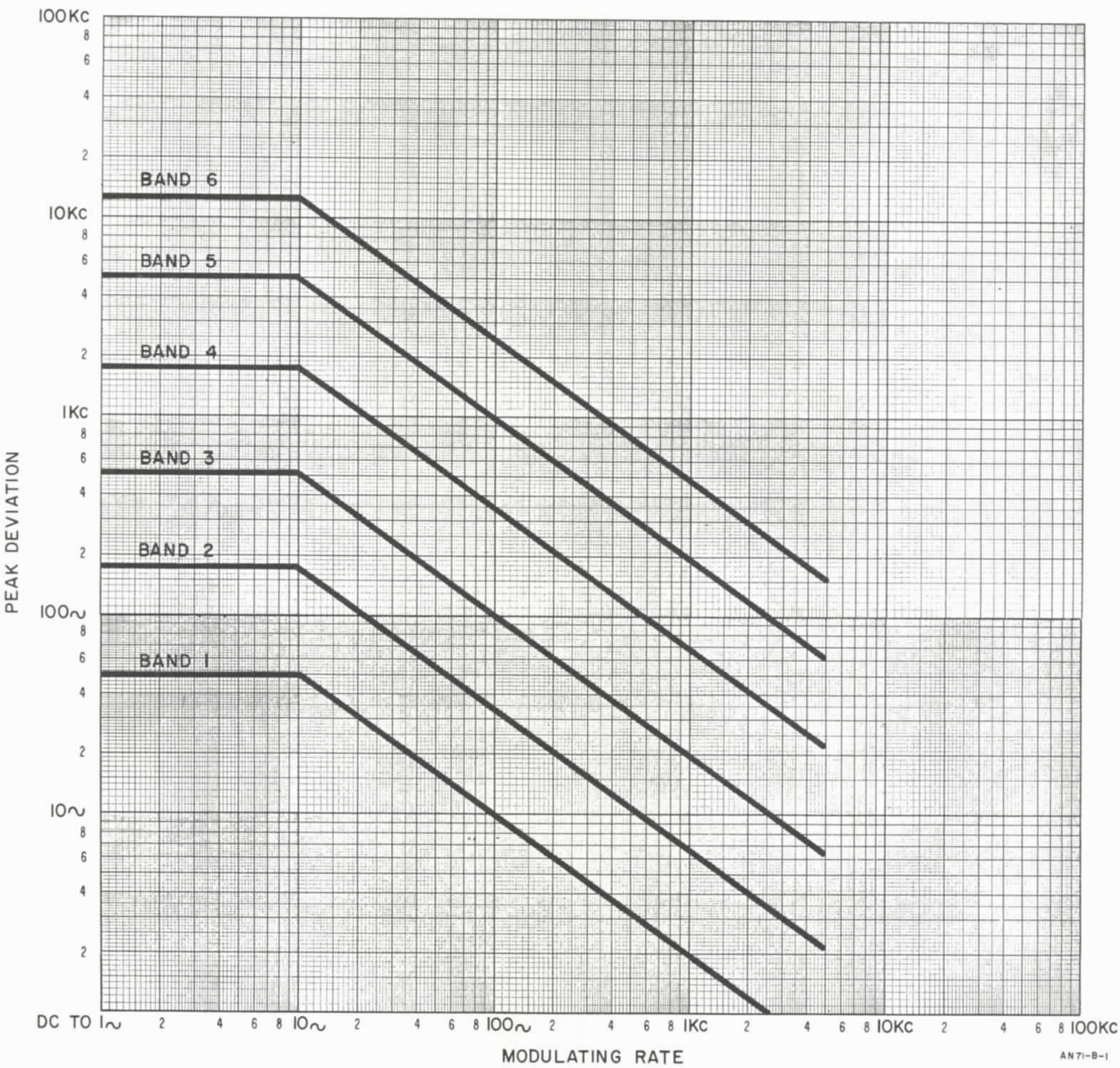



Figure 5a. Curves show limits of FM deviation vs. rate on each band for HP 606B Generator when phase locked to HP 8708A.

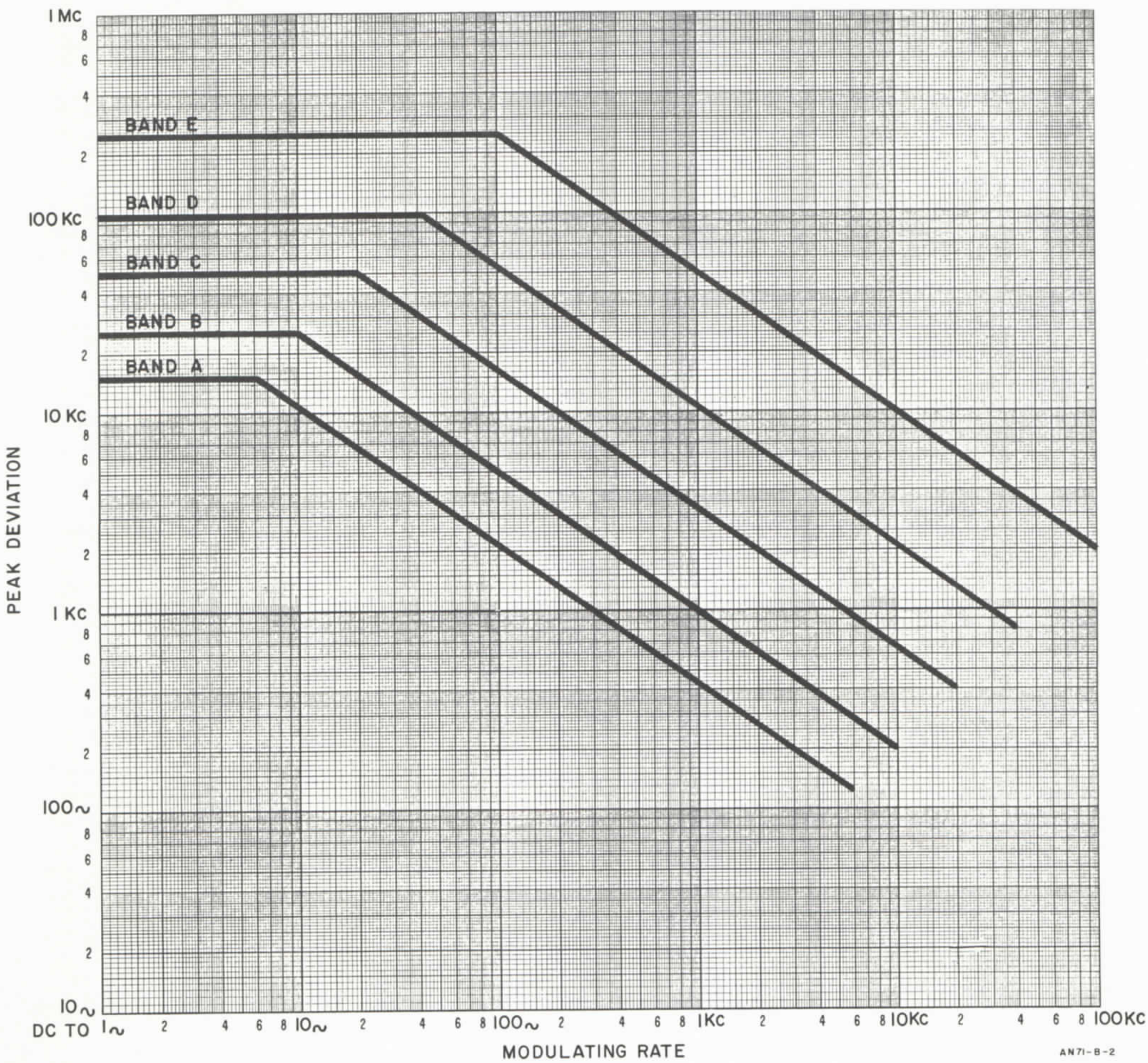



Figure 5b. *Curves show* limits of FM deviation vs. rate on each band for HP 608F Generator when phase locked to HP 8708A.

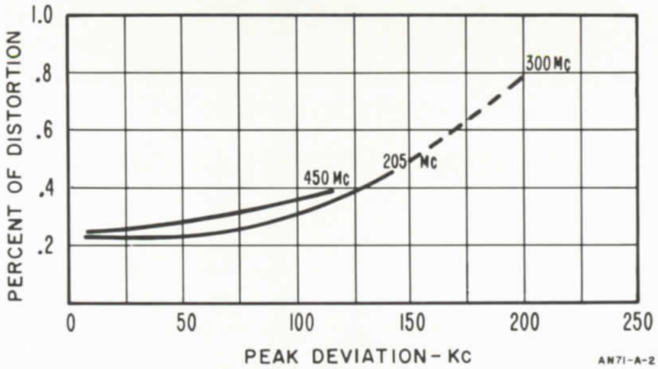



Figure 6. Typical FM non-linearity of 608F when phase locked to the 8708A.

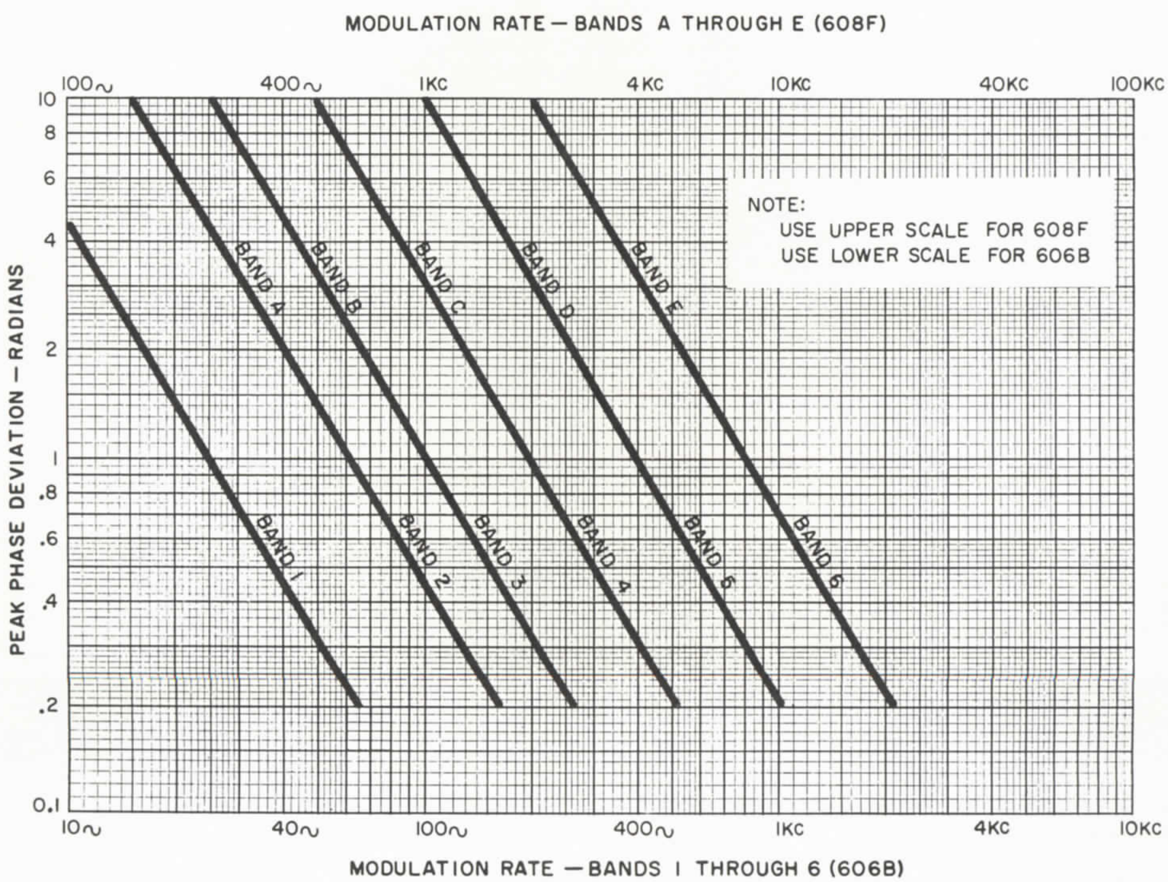



Figure 7. Limits of phase deviation vs. rate for each band of the HP 606B (numbered bands), and 608F (lettered bands) when phase locked to the HP 8708A.

# SECTION II
# THEORY OF OPERATION

## GENERAL

Figure 8 is a general block diagram of the 8708A synchronizer connected to the 608F generator.

The synchronizer contains a stable reference oscillator which operates a sampler at predetermined rates. The uncalibrated RF output from the generator is fed to the sampler where it is sampled and compared in phase to some submultiple of the reference oscillator. The phase detector output passes through a compensating circuit to voltage controlled capacitors (varicaps) in the 608F oscillator tank to maintain constant frequency. If the harmonic relationship of the generator frequency and reference tries to change, an error signal is developed in the sampling phase detector. This error signal is sensed as a compensating capacitance change in the oscillator tank of the generator. This compensation maintains a constant harmonic relationship between generator and reference so the generator frequency remains constant.

Because the generator and reference frequencies are harmonically related, tuning will be in discrete steps across each band. As the main 606B or 608F frequency dial is tuned, an error voltage is produced by the sampling phase detector which holds the generator frequency constant. If the tuning continues far enough, the system reaches the end of its lock range and can no longer compensate for the main tuning dial change. At this point the generator frequency jumps to the next harmonically related frequency of the reference. This sequence occurs throughout each band so the generator is always locked to some harmonic of the reference.

The meter on the 8708A indicates the phase error voltage being applied to the generator frequency control input. When the meter is centered, the phase lock loop is operating in the center of its locking range.

Now, in order to obtain frequencies between discrete lock points, we must be able to continuously shift the reference frequency. The 8708A reference oscillator is variable over a small range for this purpose. The variation is sufficient to overlap each harmonic so all frequencies in the 606B or 608F range may be tuned.

## SAMPLING TECHNIQUE

### SAMPLING PHASE DETECTOR

A sampling phase detector such as used in the 8708A synchronizer has two parts. One part is the sampler and the other is a zero - order hold circuit. The sampler is essentially a switch as shown in Figure 9. The switch closes for a very short time (<1 nsec) whenever a sampling pulse is applied. Each time the switch closes, a sample of the input voltage is fed to the sampler output. The zero-order hold is a capacitor on the output of the switch that holds the sampled voltage constant between samples.

If the RF input frequency is a direct harmonic of the sampling rate, then the sampler output will be a DC voltage proportional to the relative phase of the two signals. Figure 10 shows this condition.

If the input frequency or sampling rate starts to shift, the change will first appear as a phase shift and the dc level from the detector will change as shown by Figure 11.

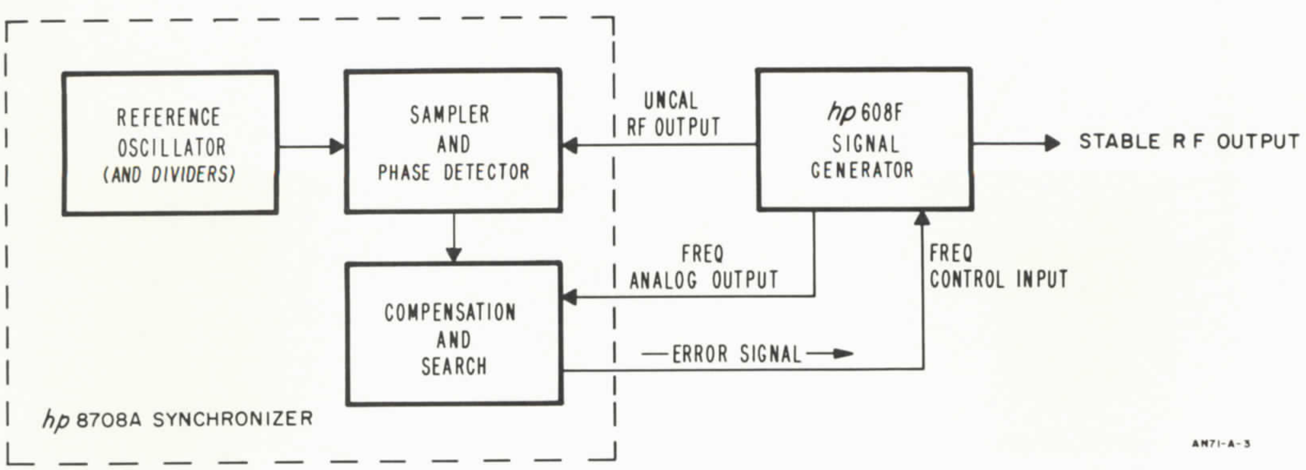



Figure 8. RF and control signal paths are shown above for the 8708A Synchronizer and 608F generator. Error voltage is generated by sampling phase detector when reference and generator RF differ in phase relation. Error voltage is applied to voltage-controlled capacity in 608F oscillator circuit to maintain constant frequency.

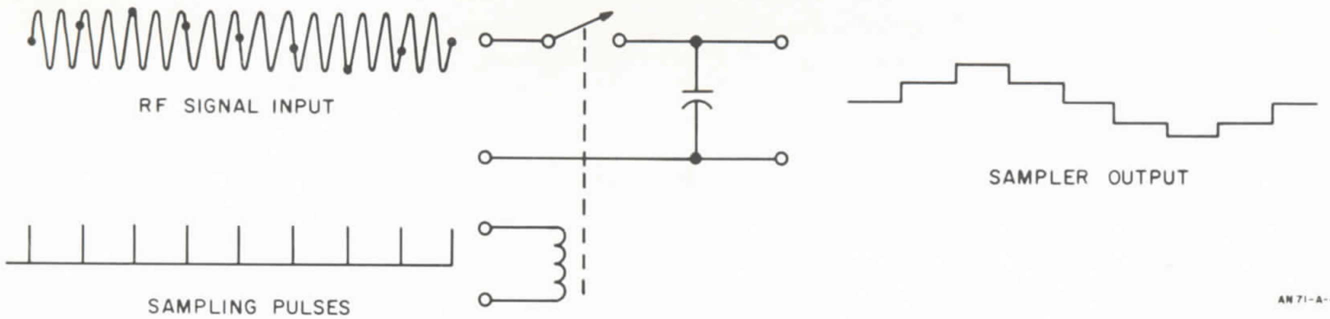



Figure 9. Equivalent circuit of a sampling phase detector shows how a step voltage is generated when the RF input signal and sampling pulses are of different phase relationship.

SAMPLING IN THE 8708A

There are two modes of sampler operation in the 8708A. When phase locking the 608F, or the 606B on Band 6 (19 - 65 Mc), the sampled frequency is furnished by the generator's uncalibrated RF output. Figure 12 shows the block diagram for this mode of operation.

The reference oscillator frequency is divided from 20 Mc, depending on band, down to the sampling rates shown in Table 1.

Table 1

| Generator | Band | 8708A Sampling Rate |
|---|---|---|
| 606B | 6 | 50 kc |
| 608F | A | 20 kc |
| | B | 50 kc |
| | C | 100 kc |
| | D | 200 kc |
| | E | 500 kc |

The frequency range switch on the 8708A corresponds to the 606B and 608F bands and selects the proper sampling rate for each band. As the generator's main tuning dial is tuned across each band, the frequency jumps at intervals equal to the sampling rate. For example; on Band B of the 608F, the output frequency will change in 50 kc steps as the tuning dial is moved continuously across the band. The 8708A meter indicates the step changes as follows; as the 608F frequency dial is changed, the meter moves continuously to the end of lock range (tail of arrows). The 8708A then locks on the next harmonic of the reference oscillator, thus shifting the RF output frequency and causing the meter indication to jump across scale. Frequencies in between are reached by adjusting the 8708A frequency tuning which changes the reference oscillator frequency. In order to maintain a harmonic relationship with the new reference frequency, the generator frequency also changes and continuous tuning is achieved.

When phase locking the 606B on Band 1 through 5, the sampled frequency is furnished by the 8708A reference oscillator as shown in Figure 13.

The uncalibrated RF output of the 606B is divided, depending on the band selected, converted to pulses, and used for sampling pulses. With this arrangement, the sampling rate and harmonic numbers remain high even though the RF frequency is low with respect to the reference oscillator.

The high sampling rate results in fast response to any attempted frequency shift by the generator. High harmonic relationship between the sampled frequency (20 Mc) and sampling rate keeps the lock points at close intervals. The close spacing allows overlapping frequency coverage and continuous tuning between lock points by changing the reference oscillator frequency.

As the 606B is tuned across each band, the output frequency ($f_c$) will jump in discrete steps. The steps

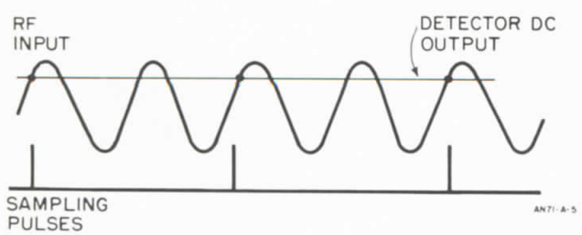



Figure 10. Sampling phase detector output is a constant DC voltage when RF input and sampling pulses are in constant harmonic and phase relationship.

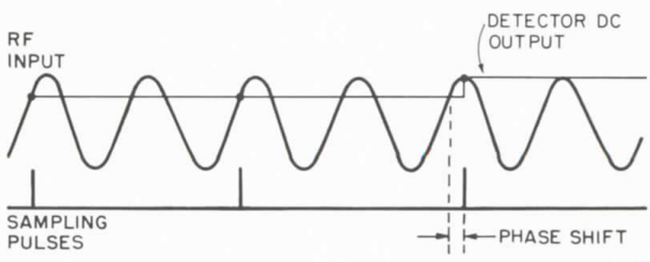



Figure 11. Phase shift between sampling pulse rate and RF input frequency causes DC voltage shift in sampling phase detector output.

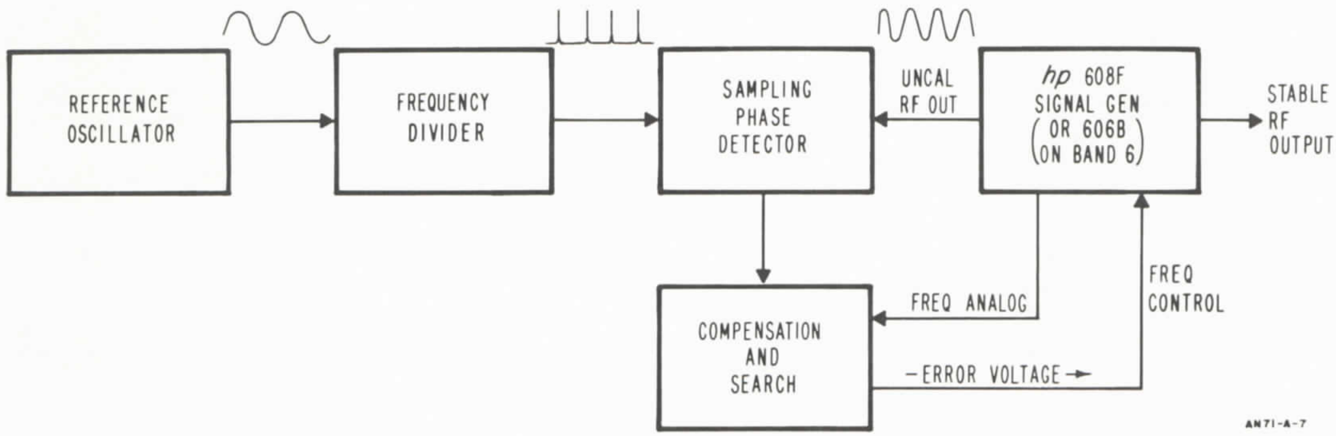



Figure 12. RF and control signal paths are shown between 8708A Synchronizer and 608F (or 606B on band 6). Reference oscillator frequency is divided and converted to sampling pulses to operate phase detector. Generator frequency is maintained constant by applying phase detector output voltage to voltage-controlled capacitors in generator's oscillator circuit.

vary from approximately .1% $f_c$ at the low end of each band to .3% $f_c$ at the high ends as shown in Table 2. For example, at 50 kc (Band 1), the steps are in 62 cps increments while at 170 kc, the steps are 720 cps apart. Frequencies in between are reached by changing the 8708A reference frequency (FREQUENCY TUNING). The 8708A meter indicates incremental frequency shift in the same manner described for 608F operation.

Table 2

| Generator | Band | Divider | 8708A Lock Intervals $= \frac{(f_{606B})^2}{(2 \times 10^7)(\text{divider})}$ |
|---|---|---|---|
| 606B | 1 | ÷2 | 62.5 cps - 720 cps |
| | 2 | ÷8 | 170 cps - 2 kc |
| | 3 | ÷25 | 562 cps - 6.48 kc |
| | 4 | ÷80 | 1.93 kc - 22.5 kc |
| | 5 | ÷250 | 6.73 kc - 73.7 kc |

## COMPENSATION AND SEARCH

COMPENSATION.

The phase lock loop is a high gain feedback system which is subject to noise and instability. The effects of noise and instability can be minimized, however, by controlling frequency response and phase shift with compensation circuits in the phase lock loop.

In the 8708A, compensation is placed in the phase detector output. Because each band uses different sampling rates, the compensation differs for each setting of the 8708A Frequency Range Switch. This provides optimum loop response on each band and serves to filter out sampling pulses from the phase detector output.

An amplifier in the compensation circuits is used to control overall loop gain. At higher RF frequencies, less DC voltage is required by the oscillator varicaps

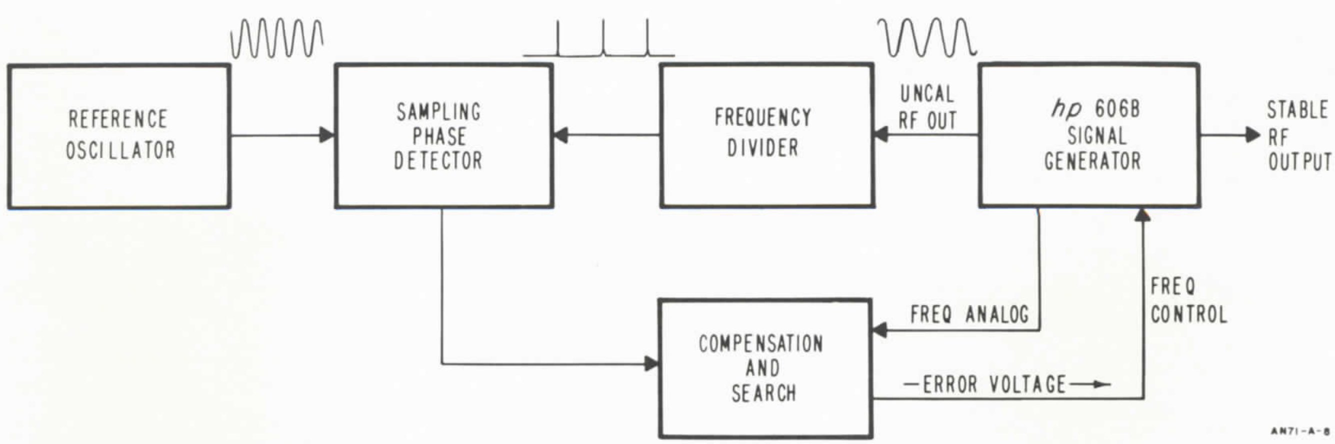



Figure 13. On bands 1 through 5 of the 606B (50 kc - 19 Mc), sampling pulses are derived from the generator RF. Sampled frequency is furnished by the 8708A reference oscillator, and a control voltage is developed by the phase detector to stabilize the 606B oscillator. This arrangement keeps sampling rate and harmonic numbers high, even though RF frequency is low with respect to the 8708A reference oscillator.

to change frequency a given amount. The FREQUENCY ANALOG output from the generator is fed to this amplifier, maintaining a constant $\Delta f$/volt coefficient throughout each band.

SEARCH.

A low frequency search oscillator is included in the frequency control output of the 8708A to assure automatic phase lock. When the system is not locked, the search oscillator swings the frequency control voltage to the generator back and forth across its range. When the generator frequency approaches a harmonic of sampling frequency, the system phase locks and the search oscillator ceases to operate. When the system is unlocked, searching is indicated by the continuous back and forth action of the 8708A panel meter. Searching should not occur after the generator and synchronizer are properly interconnected, and the frequency range switches of both instruments agree.

## MAIN LOOP FREQUENCY DIVIDER

A series of binary frequency dividers are used in the 8708A to derive the various sampling rates from the reference oscillator or generator (606B). These binaries comprise the Main Loop Frequency Divider shown previously as the "Frequency Divider" in Figures 12 and 13.

The dividers are automatically selected by the 8708A FREQUENCY RANGE switch for optimum sampling rate for the band in use. Recall that the interval between lock points is proportional to the sampling rate, i.e. as sampling rate increases, the lock points become further apart in frequency. If this interval becomes too great, the lock points may fall outside the range of the varicaps and phase lock could not be obtained.

On the other hand, high sampling rates give higher loop bandwidth for faster response to attempted frequency changes caused by microphonics etc. The main loop divider selects the division giving highest sampling rate consistent with lock point intervals within the varicap range.

## REFERENCE LOOP

The reference oscillator in the 8708A is actually three oscillators in a separate phase lock loop as shown in Figure 14.

The purpose of this arrangement is to obtain a stable reference frequency which is variable over a ±50 kc range so continuous tuning is possible between lock points. The stability of a VFO at 20 Mc would not suffice. A crystal oscillator at 20 Mc could not be pulled sufficiently. Simply mixing a crystal controlled oscillator frequency with a low frequency VFO would produce undesirable mixing products.

In the 8708A, the outputs of a crystal controlled oscillator (19.65 Mc) and voltage controlled LC oscillator (19.95 - 20.05 Mc) are mixed and fed thru a low pass filter. The filter passes only the 300 - 400 kc difference frequency of the two oscillators to a sampling phase detector. Sampling rate is established by a 300 kc - 400 kc VFO; thus a sample is taken for every cycle of input. The phase detector output locks the LC oscillator to the sum of the 19.65 Mc crystal oscillator and VFO frequencies. When the VFO frequency is shifted by the FREQUENCY TUNING control on the 8708A, the LC oscillator frequency follows, and contінous tuning over a ±50 kc range is achieved.

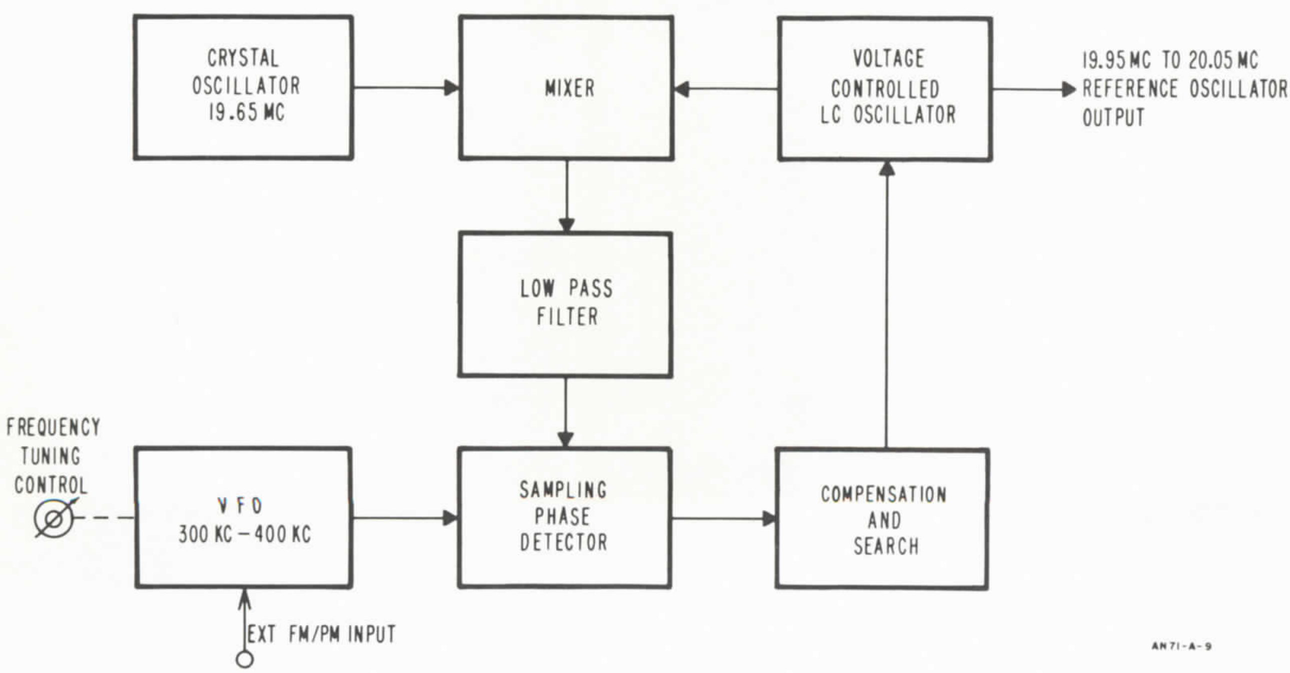



Figure 14. Reference oscillator in 8708A is actually a phase locked LC oscillator with a crystal and VFO reference. This design provides a stable 20 Mc reference frequency which is variable over a ±50 kc range and is free of undesirable mixing products.

Overall stability of the reference is determined by both the crystal oscillator and VFO. The crystal oscillator and VFO are placed in an oven for stabilization to $2/10^7/10$ minutes after an initial warm up of 1/2 to 1 hour. Figure 15 compares the 608F frequency drift on each band for unlocked, and phase locked operation. Note the different span calibrations for frequency.

The VFO stability is the ultimate limitation to overall reference stability. Because the VFO generates only a small percentage of the total reference frequency, its drift effect is relatively small. If greater stability is desired, an external 20 Mc frequency standard can be substituted for the entire reference oscillator. This standard could be derived from an hp 106A Quartz Oscillator for $1.5/10^{11}$ short term stability. This stability would be maintained in the locked 606B or 608F output frequency. However, continuous tuning between lock points would not be possible. A frequency synthesizer could provide the high stability variable reference for continuous tuning capability.

## FM AND PHASE MODULATION

The VFO frequency, or phase, in the 8708A reference loop may be varied by applying an external voltage to the MODULATION INPUT. Any change in VFO frequency changes the RF output frequency of the generator. This provision may be used to FM or phase modulate the 606B or 608F over narrow bands with exceptional linearity.

The deviation and rate of modulation depends upon the overall loop bandwidth of the phase lock system. See Figures 5, 6 and 7 for deviation, rate, and typical modulation linearity.

Peak-to-peak deviation may be monitored by connecting an oscilloscope to the 8708A Deviation Monitor jack, and observing the error voltage amplitude in the phase lock loop. This output may be pre-calibrated at specific RF frequencies of interest for voltage vs. deviation. This calibration will vary with each generator and RF frequency but is useful in repetitive tests at specific frequencies. If preferred, an FM deviation monitor may be connected through a BNC tee to the UNCAL RF output of the generator for direct readout.

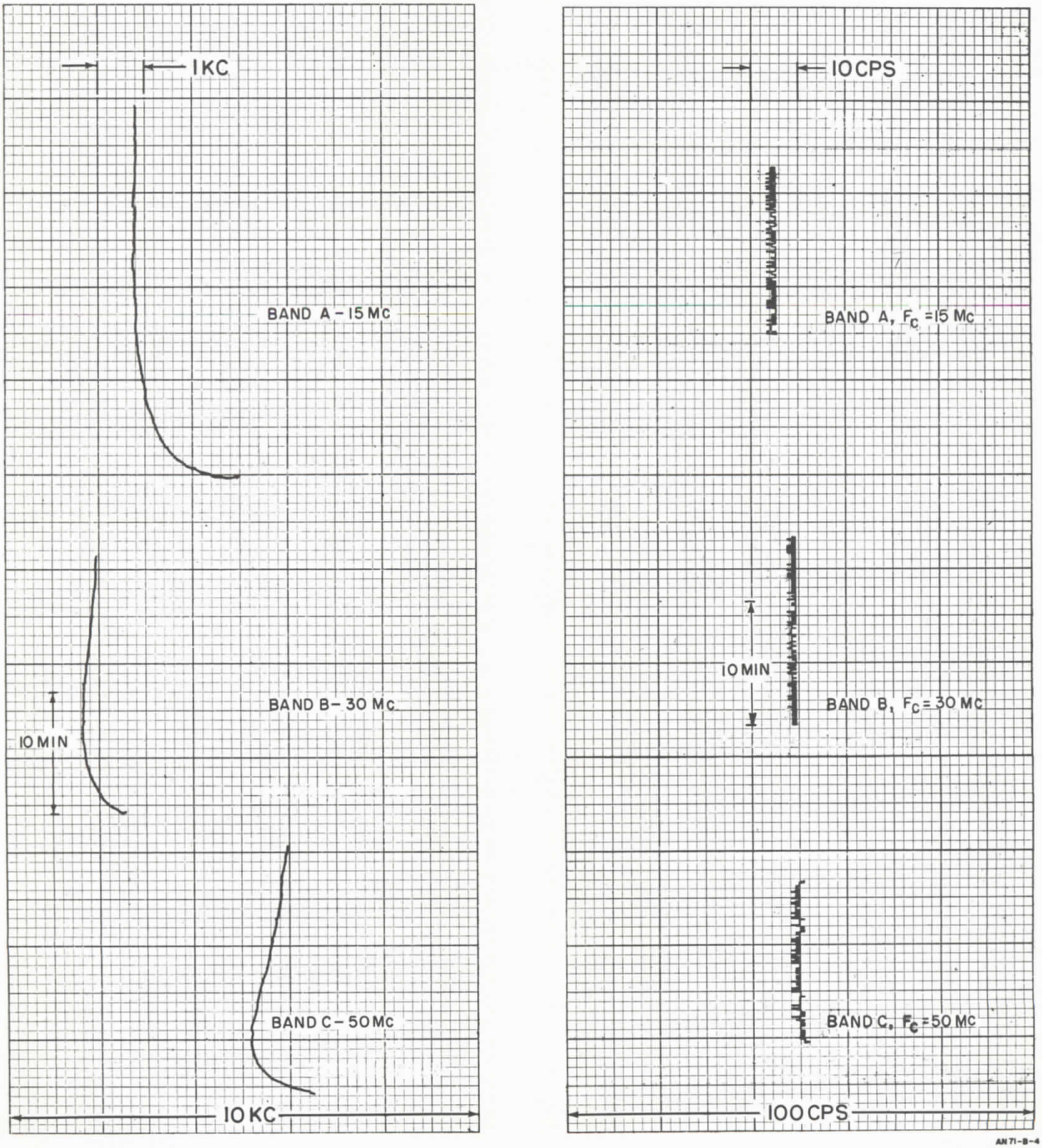



Figure 15a. Strip chart recordings compare frequency stability of hp 608F on three bands for unlocked (left), and phase-locked (right) operation. Note different span calibrations for frequency; span sensitivity increase of 100 in right hand recording magnifies ±1 count ambiguity of counter causing fine grain variations. Also note time to restabilize after band switching when unlocked.

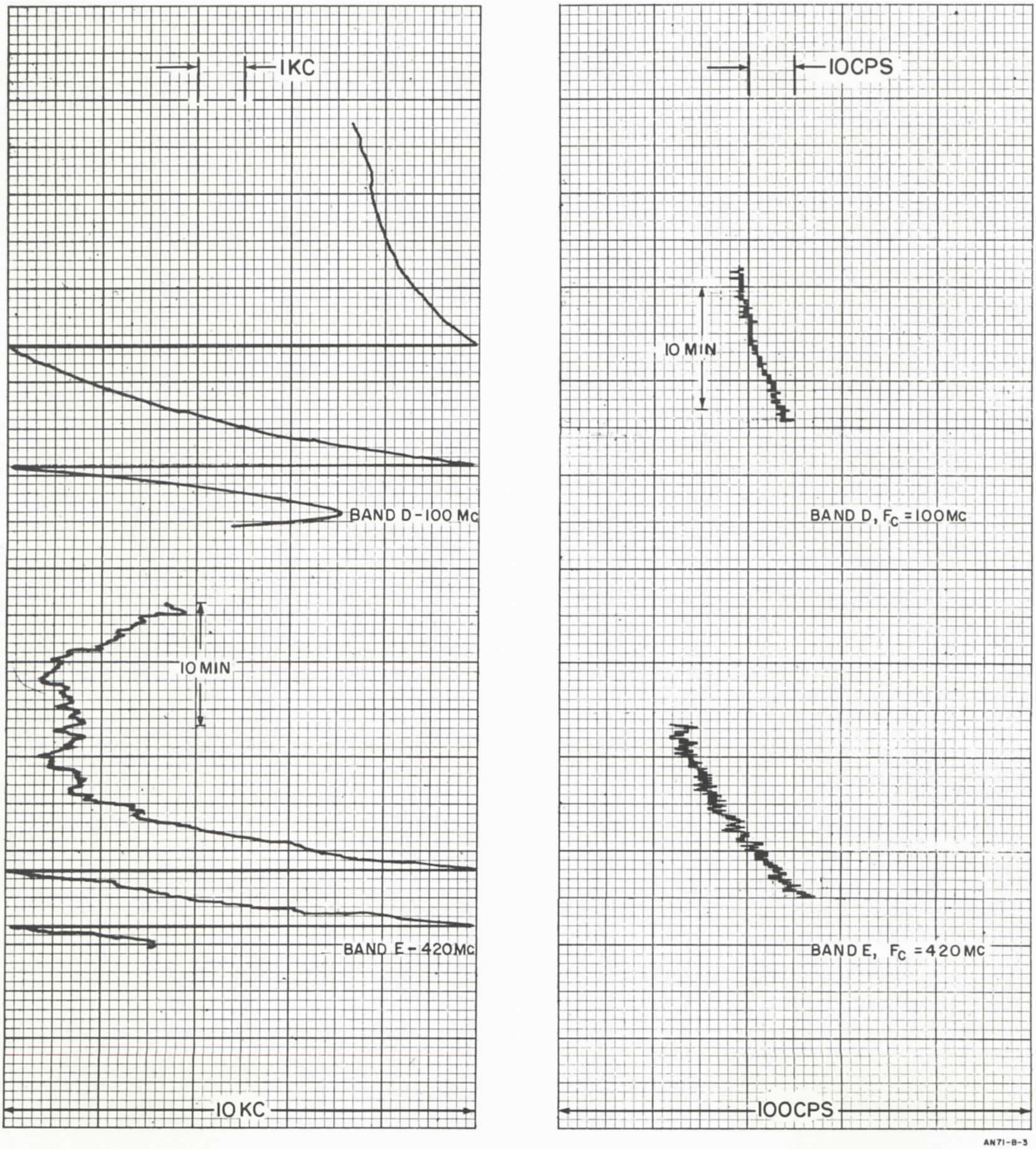



Figure 15b. Frequency stability of hp 608F on top two bands for unlocked (left), and phase locked (right) operation. Note span calibrations. Sudden full-scale excursions on unlocked record result when frequency reaches scale limits. Drift then continues in same downward direction.

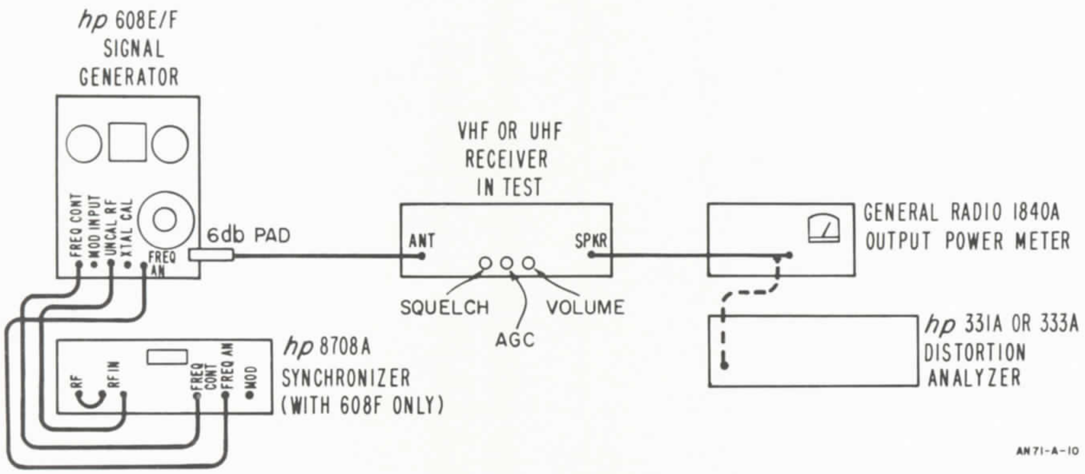



Figure 16. Connect equipment as shown to test AM receivers at VHF. Use 608F/8708A for $2/10^7/10$ minute frequency stability and high tuning resolution. For less critical applications omit 8708A and use the HP 608E signal generator.

# SECTION III
# APPLICATIONS

## RECEIVER TESTING

Designing and testing a communications or data receiver requires specific performance checks using a signal generator. These checks are usually made under test conditions generally agreed upon by the communications industry. Special tests may also be required in certain applications such as the receiver design phase.

The 606B and 608E/F signal generators are ideally suited to receiver testing because of their frequency and amplitude accuracy, stability, and convenience. The 8708A synchronizer may be added, as required, to either the 606B or 608F for increased frequency stability or FM capability.

AM RECEIVERS - HF-VHF.

AM receiver performance in the HF-VHF bands can be checked using the equipment setup shown in Figure 16.

The choice of generators 608E or 608F/8708A, depends on the particular receiver design and type of tests being made. Multi-channel VHF receivers with 50 kc - 100 kc channel spacing, for example, will ordinarily be satisfied with the 608E. In some applications, the precise frequency control of the 608F and 8708A will be welcome companions to the features of the 608E. One such application is the bandpass check of a VHF receiver over a 70 kc range to assure reception of sub-carrier telemetry. In this case, the generator must be set to a number of closely spaced RF frequencies and the receiver response noted at each point. In addition to settability beyond ordinary requirements, the generator must remain stable within about 100 cps at 300 Mc. The 608F/8708A satisfies these additional requirements.

SENSITIVITY. The sensitivity of a receiver is its ability to receive weak signals. Therefore, the signal generator must be well shielded to prevent stray radiation, and provide accurate RF output levels in the microvolt region for valid tests. The ±1 db attenuator accuracy and low leakage of the 608E/F is essential to such tests.

Accurate sensitivity and signal plus noise-to-noise tests also depend on low incidental FM in the signal generator. Otherwise the generator output will have to be increased to compensate for power lost in FM sidebands which are outside the receiver passband. This loss appears in the resulting checks as a loss in receiver sensitivity. The buffered oscillator in both 608E and F keeps peak incidental FM below 1 kc for accurate receiver checks. When the 8708A synchronizer is used, incidental FM is further reduced by the phase lock feedback action.

Using the setup of Figure 16, measure receiver sensitivity at the desired frequency and prescribed modulation. With the 608E/F AMPL TRIMMER peaked and the OUTPUT LEVEL calibrated, adjust the RF attenuator for rated audio power out of the receiver. Receiver sensitivity, in terms of microvolts into 50 Ω, is one half the 608E/F attenuator reading because of the 6 db pad. Sensitivity in terms of open circuit voltage is equal to the attenuator reading.

SIGNAL + NOISE-TO-NOISE RATIO. Receiver sensitivity is usually associated with a specification of signal plus noise-to-noise ratio. Signal plus noise/noise can be checked by noting the receiver audio output change, in db, between a modulated and unmodulated condition in the generator. The RF and modulation levels required for this test are commonly specified by the receiver manufacturer.

DISTORTION. Maximum non-linear distortion in a receiver is often specified at 10%; some are rated at 5%. If the signal generator has AM distortion, it degrades the receiver distortion check; AM distortion in the 608E/F is two to three times lower than older generators even at high modulation percentages, resulting in a better test margin for receiver distortion tests.

Receiver distortion can be measured with an hp 331A or 333A Distortion Analyzer connected to the audio output meter terminals as shown in Figure 16. Set the generator output and MODULATION LEVEL as specified by the receiver manufacturer for distortion measurement. (The modulation percentage for distortion checks is often 80 to 90%.) Be sure the 608E/F frequency is tuned for maximum receiver output, and that the AMPL TRIMMER is peaked. Measure harmonic distortion in the receiver output with the hp 331A/333A.

If desired, receiver distortion may be checked throughout the audio range. Connect an hp 200CD audio oscillator to the 608E/F AM/PULSE MOD input and set the MODULATION switch to EXT AM. Adjust the audio oscillator level and frequency for desired AM in the 20 cps - 20 kc range and check receiver distortion.

AGC AND SQUELCH. The receiver manufacturer usually specifies a range of RF input voltage over which the AGC will control the audio output level. This range is typically a few microvolts to 0.5 or 1 volt of RF for 1 to 3 db change in audio output. The 608E maximum output rating is 1 volt, satisfying high level requirements for AGC tests, yet it includes a buffer stage for low incidental FM. The 608F, also buffered, is rated at 0.5 volt maximum output. However, the F typically will deliver 1 volt of RF across most of the instruments' range.

Checking squelch action requires the repeatability of low level RF settings as provided by the 608E/F calibrated attenuator.

The squelch circuit is usually the last item to be checked because its action would interfere with the sensitivity test and other measurements. Final squelch setting will depend upon the noise level at the receiver input when an antenna is connected. However, the signal generator can be used to check the squelch action to assure proper opening and recovery when a low level signal is applied, then removed.

OTHER AM RECEIVER TESTS. A number of other receiver tests may be made with the 608E/F in addition to those discussed here. Image rejection and spurious responses are important characteristics which may be checked with the setup of Figure 16. Pulse modulation may also be applied to the 608E/F for precise checks of squelch and AGC reaction time. Selectivity measurements are easily accomplished at VHF using the 608F and 8708A synchronizer with an electronic counter such as the hp 5245L.

SINGLE-SIDEBAND RECEIVERS - HF.

Single-sideband (SSB) receivers impose some of the greatest frequency stability requirements encountered in receiver testing. Any shift of generator RF frequency is directly translated to an equal shift in receiver audio output frequency. This shift can easily go beyond the receiver's narrow passband unless the generator is very stable.

The hp 606B and 8708A eliminates objectionable drift, microphonics, and frequency resolution problems of older generators which were designed for standard AM receiver testing. The 606B/8708A has continuous tuning, with automatic phase lock, simplifying and speeding SSB receiver testing throughout the common 2-30 Mc band. Frequency accuracy and settability is enhanced by using an hp 5245L counter as shown in Figure 17.

This setup can be used to check receiver sensitivity, bandwidth, frequency accuracy, AGC, etc. Two-tone tests can be made using the hp 10514A Double Balanced Mixer and an audio oscillator as shown in Figure 17. The mixer rejects the 606B carrier by at least 40 db and passes two equal amplitude sidebands spaced twice the audio oscillator frequency apart. The 606B and 204B can be tuned so the two sidebands are separated by a specific frequency within the receiver passband as shown in Figure 18. Then the 302A analyzer measures intermodulation products in the receiver output. Specifications on the hp 10514A Double Balanced Mixer are given in the Technical Data sheet available from your HP sales office.

FM RECEIVERS - VHF AND UHF.

One of the most dramatic contributions of the 608F/8708A to FM receiver testing is very good linearity

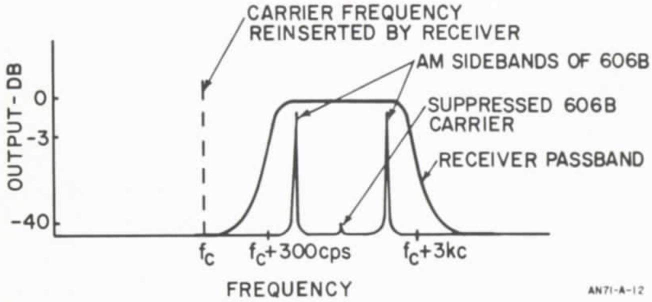



Figure 18. Plot shows single-sideband receiver passband with 2-tone test signal superimposed. Separation of sidebands is controlled by the audio oscillator frequency using the setup of Figure 17. Sideband pair is tuned into receiver passband with 606B/8708A Frequency Tuning.

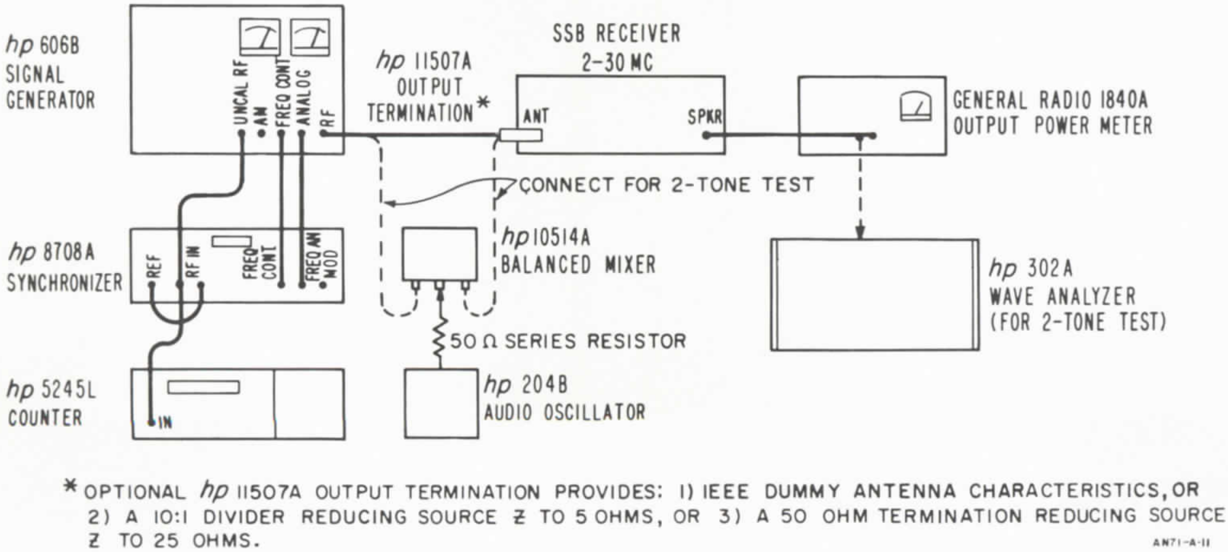



Figure 17. Single-sideband receiver tests are easier and more accurate when generator drift and microphonics are eliminated by the phase-locked test setup shown. A counter enhances the system by giving direct frequency readout to 1 cps for checking receiver tuning accuracy. Audio oscillator and HP balanced mixer provide 2 tone modulation with carrier suppression of at least 40 db.

and low residual FM. FM linearity is better than 1% and residual FM is low enough to make 50 db quieting tests on narrow-band receivers. Narrow-band FM receivers in the VHF - UHF bands typically require 3 kc deviation at modulating frequencies up to about 3 kc maximum. As Figure 5b shows, these deviations and rates are possible on Bands D and E of the 608F, i.e., 95 - 455 Mc. This range includes the very active 150 Mc and 450 Mc mobile two-way FM bands where narrow-band modulation is required.

Figure 19 shows the setup for checking FM receiver performance with the 608F/8708A. The modulating signal is furnished by an hp 200CD audio oscillator connected to the 8708A MODULATION INPUT. An FM deviation monitor, connected to the 608F UNCAL RF OUTPUT through a tee, is used to set up specific deviations. Sensitivity, quieting, adjacent channel rejection and other tests on narrow-band systems can be made accurately with this system. AM suppression tests are simplified because AM and FM can be applied to the system of Figure 19 simultaneously.

DEVIATION MONITOR OUTPUT. The DEVIATION MONITOR jack on the 8708A should not be confused with a direct reading deviation monitor which operates from an RF signal. When using a direct reading FM monitor with the 8708A, it should be connected to the generator's UNCALIB RF output through a BNC tee as shown in Figure 19.

For indirect FM monitoring, the 8708A feeds the modulating waveform out of the DEVIATION MONITOR jack for viewing on an oscilloscope. To calibrate the DEVIATION MONITOR output, connect the equipment as shown in Figure 20. Set the 8708A MODULATION switch to FREQ and the AC/DC switch to DC. Turn MODULATION LEVEL fully clockwise. With the DC power supply off, note the counter reading. Increase the power supply voltage in discrete steps, noting the frequency change on the counter vs. the voltmeter reading. When the 0 to -10 volt range has been covered, you will have a table of DC or peak AC volts vs. frequency deviation for that particular RF frequency.

Another method for checking FM deviation is to monitor peak voltage of the modulating signal into the 8708A. Deviation sensitivity is 10 kc/volt x $\frac{f_c\ (\text{Mc})}{20}$. This coefficient expresses the peak deviation corresponding to a DC or peak AC voltage applied to the 8708A MODULATION INPUT at any carrier frequency $f_c$ (with the MODULATION LEVEL control at maximum clockwise position). For example, at a carrier frequency of 150 Mc the FM deviation corresponding to the peak AC voltage at the MODULATION INPUT jack would be:

$$10\ \text{kc/volt} \times \frac{150}{20} = 75\ \text{kc/volt.}$$

SPECTRAL DISPLAYS OF FM. A spectrum analyzer, such as the hp 851B/8551B, can also be used to check deviation at low modulation indexes. Spectral displays of a low modulation index are shown in Figure 21 along with graphs showing sideband-to-carrier amplitude vs. modulation index. This technique is especially useful for checking deviations when the modulation index is too low for the Bessel null method.

Applications of the 608F/8708A to phase modulation receivers have not been fully explored at this time. Phase modulation and spectral purity specifications are listed for the 8708A for consideration by PM receiver users. There is indication that PM receivers with narrowband tracking filters can benefit from the 608F/8708A frequency stability. Residual FM in some generators is large enough to exceed the tracking filter bandwidth and the receiver in test drops out of lock.

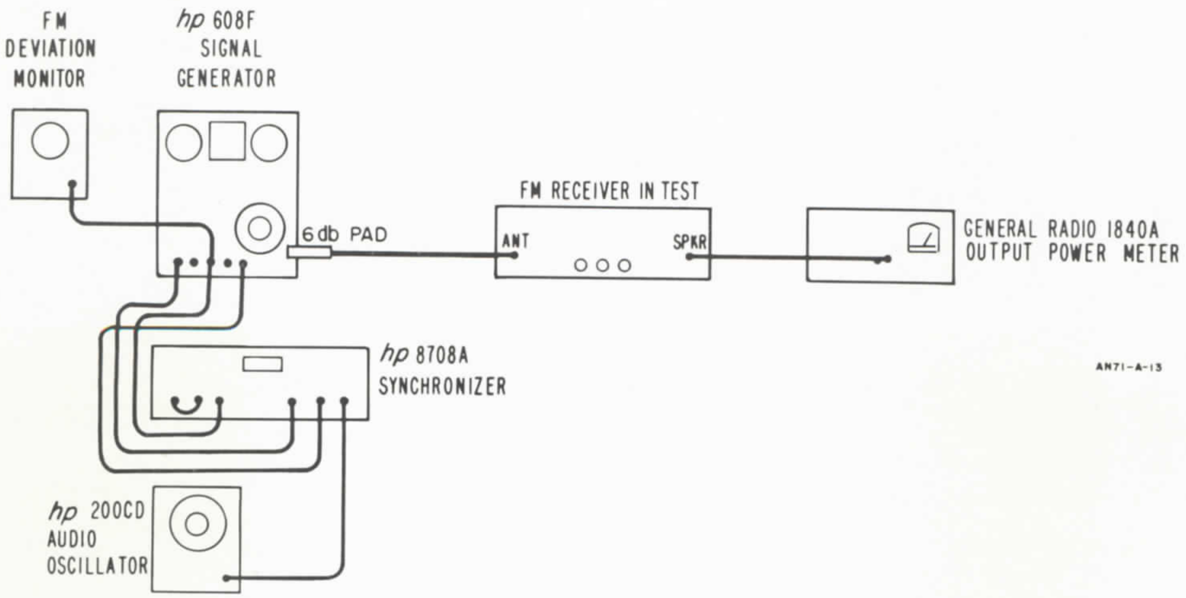



Figure 19. Narrow band FM receivers typically used in the 150 Mc - 450 Mc bands can be checked for quieting up to 50 db using this system because of low residual FM in phase-locked signal generator. Deviation sensitivity, AM suppression, linearity and other checks may also be made accurately for complete receiver checkout.

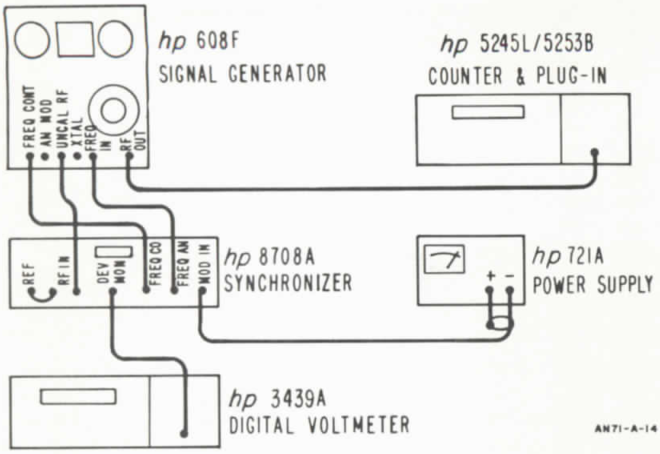



Figure 20. Deviation monitor output on 8708A can be calibrated accurately in terms of peak voltage versus deviation, using setup shown. External power supply furnishes 0 to -10 volts to MODULATION INPUT. DVM reads deviation monitor output voltage, and counter measures corresponding RF frequency changes. After calibration, an oscilloscope can read Peak AC voltage of modulating signal at monitor output to determine FM deviation. Calibration must be repeated for different RF frequencies.

## AMPLIFIER TESTS

RF, IF, and broadband amplifier testing in the 50 kc - 480 Mc bands is easier and faster due to automatic output leveling in the 606B and 608E/F Signal Generators. Leveled RF output simplifies amplifier tests of gain, frequency response and distortion by eliminating repeated output adjustments at each frequency. Both generators have high level output for driving intermediate amplifier stages or low input impedances where signal level is reduced by a matching network.

### IMPEDANCE CONSIDERATIONS

Both the 606B and 608E/F Signal Generators have output calibrations in voltage or dbm at 50 ohm impedance. This is a common transmission line impedance for RF, but is by no means the only impedance a signal generator must work into. Amplifier testing is a prime example of this situation. Often the amplifier in test has a higher input impedance than the generator. This higher impedance, if uncompensated, results in a higher voltage developed at the amplifier input than indicated by the generator. The two extremes, of course, would be 1) twice indicated voltage when operating into an infinite impedance, and 2) zero volts into a short. Accessory terminations are listed in Table 3 to adapt the 606B and 608E/F to various load impedances while maintaining output calibration accuracy.

The 606B termination has three switch selected output impedances for driving either higher or lower impedance circuits.

Voltages read on the 606B must be corrected according to the impedance being driven. For example, suppose an amplifier with 72 ohm input impedance is being checked for voltage gain using the 606B. The equipment could be set up as shown in Figure 22 with the 11507A termination set to 5Ω. (Inset shows load detail.)

When the 606B termination is set to 5Ω, and operating into an infinite impedance, the voltage division is 10:1. In this test, the 72 ohm amplifier impedance shunts the 5 ohm source impedance by a small amount so the voltage division is not exactly 10:1.

The actual division can be found for non-reactive loads using Ohm's law and taking a simple ratio as follows:

$$R_L = \frac{R_2 R_3}{R_2 + R_3}$$

$$R_T = R_1 + R_L$$

where

$R_L$ = driven load resistance

$R_T$ = total load resistance to 606B

Therefore, the voltage division is the ratio

$$\frac{E_{IN}}{E_L} = \frac{R_T}{R_L}$$

Substituting terms and simplifying gives the general expression:

$$\frac{E_{IN}}{E_L} = \frac{R_1 (R_2 + R_3)}{R_2 R_3} + 1$$

Applying the actual resistances given for this example, the ratio is:

$$\frac{E_{IN}}{E_L} = \frac{45 (5 + 72)}{5(72)} + 1 = 10.62:1$$

Table 3

| Generator | Accessory Termination | Input/Output Impedance |
|---|---|---|
| hp 606B | hp 11507A | 50Ω input/three position output; 50Ω, 5Ω (10:1 voltage division), IRE Standard Dummy Antenna (driven from 10:1 divider). |
| hp 608E/F | hp 11508A | 50Ω/50Ω, for injecting signals into high impedance circuits |

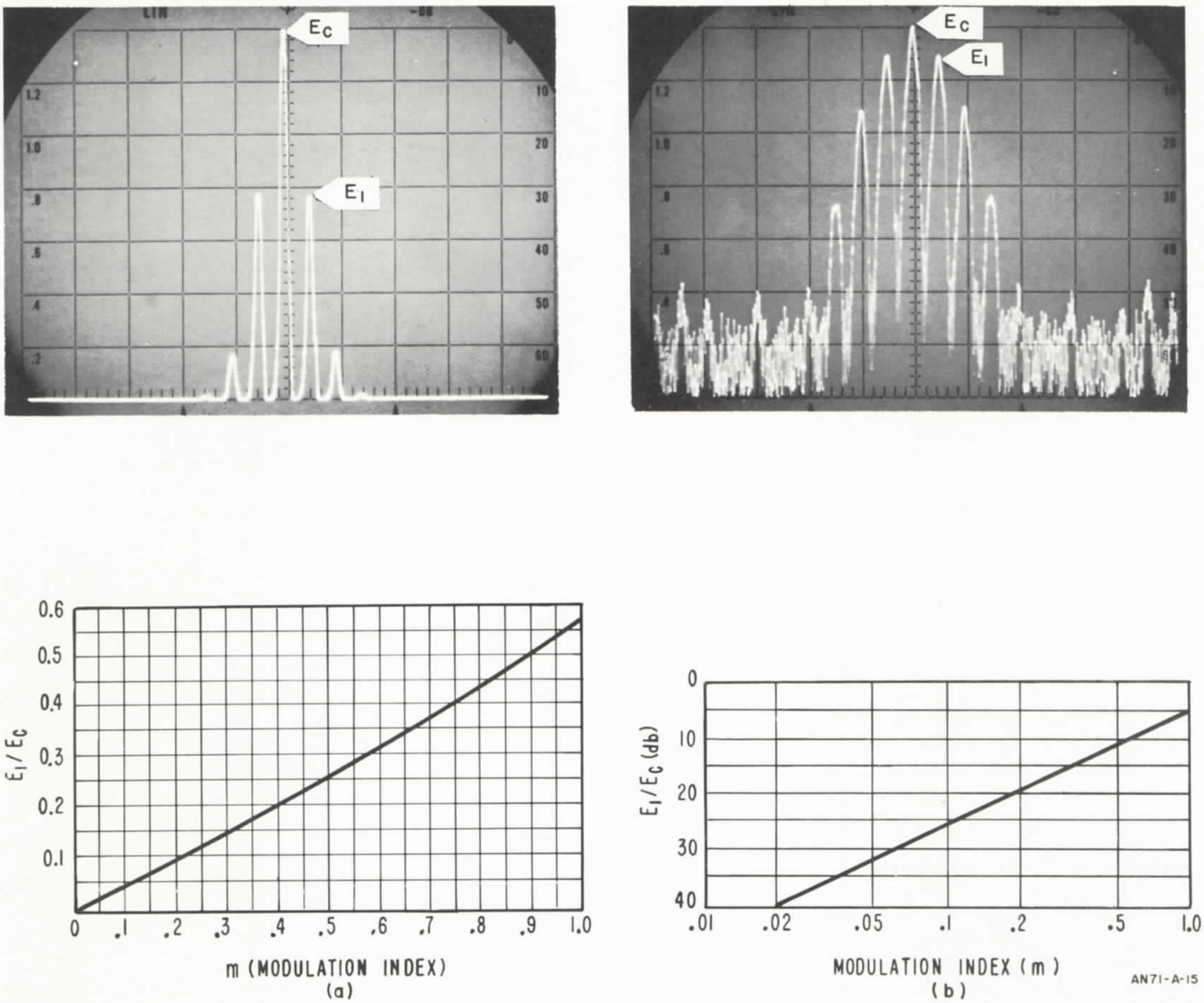



Figure 21. Spectrum Analyzer displays of 608F/8708A with 5 kc FM, 4.75 kc deviation. First order sideband-to-carrier amplitude ratio is measured on (a) linear or (b) log (10 db/cm) display. Ratio is entered on appropriate graph to find modulation index (m). Carrier deviation is m x modulation frequency.

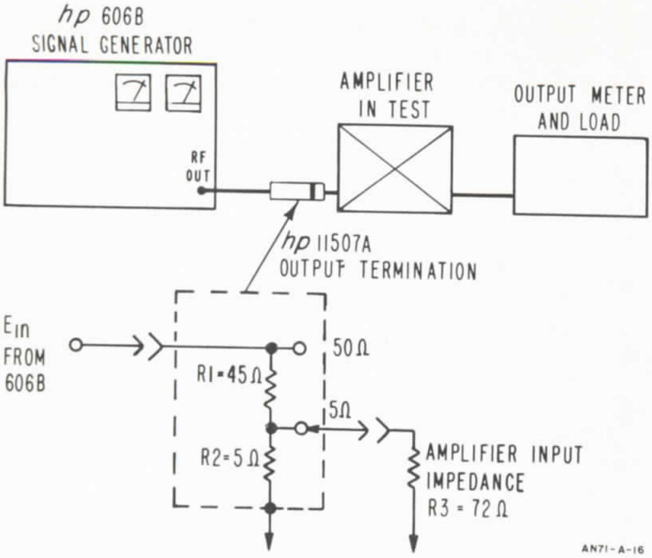



Figure 22. Amplifier with 72 ohm input is driven with HP 606B Generator through accessory termination (circuit detail shown). Switch selected output impedances give flexibility for driving other than 50 ohm loads while retaining output voltage accuracy.

Thus, the actual voltage into the amplifier being tested, is the 606B output reading divided by 10.62.

In most cases, this division is close enough to allow a convenient 10:1 factor to be applied. However, the example illustrates how different impedances affect output voltage calibration.

The 608E/F output termination is a 50 ohm resistive load connected to a coaxial cable. This accessory is convenient for injecting signals into high impedance loads. If the driven impedance is high enough, its shunting effect on the 50 ohm load is small and the 608E/F output can be read directly without correction.

## BALANCED AMPLIFIER INPUTS.

Both the 606B and 608E/F have single-ended RF outputs. When testing amplifiers with balanced inputs, a balanced-to-unbalanced transformer (balun) or matching pad is required. Baluns offer very low loss and truly balanced outputs. Broadband baluns in the 606B and 608E/F frequency range can be built using toroids.

Figure 23 shows details of a balun for 50 ohm unbalanced to 300 ohm balanced operation. It is useful with the 606B from about 100 kc to 20 Mc. Baluns for other impedances can be built using different turns ratios.*

Pads can also be built up for balancing and impedance matching using a resistor network**. A typical resistor arrangement for 50 ohm unbalanced to 300 ohm balanced operation is shown in Figure 24.

*See C. L. Rutheroff, "Some Broadband Transformers", Proc. IRE, Aug '59, p. 1337.
**Reference Data for Radio Engineers, 4th Ed. International Telephone and Telegraph Corporation, (1956).

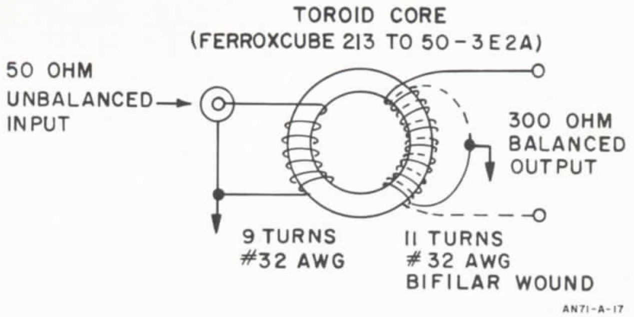



Figure 23. Balun constructed with toroid core matches 50 ohm unbalanced generator output to 300 ohm balanced line. Bifilar secondary minimizes electro-static coupling from primary to preserve balance.

The 6 db loss caused by this pad is usually not serious because both the 606B and 608E/F generators provide high level output.

## SPURIOUS OUTPUTS AND AMPLIFIER DISTORTION.

The ideal amplifier faithfully reproduces any input signal within a specified passband. Additional output signals can be produced if there is distortion in the amplifier. If the distortion is excessive, the amplifier becomes a troublesome source of interference.

RF amplifier distortion can be measured with a spectrum analyzer or a wave analyzer (hp 302A, 310A) as shown in Figure 25, depending on the frequency range of interest.

The signal generator output must be comparatively "clean" to avoid distortion measurement errors. Harmonics or other spurious from the generator, which are in the amplifier passband, will be included in the output, and increase the apparent amplifier distortion.

Figure 26 is a spectral display of the fundamental and harmonics from a 608F at two random frequencies. Note the second harmonic is the only spurious output present in both cases, and they are 43 db and 48 db below the fundamental respectively. This corresponds to 0.7% and 0.4% of the desired signal voltage.

Typical distortion specifications on RF amplifiers at VHF and UHF are 5 to 10% so the 608E harmonics noted here could be ignored.

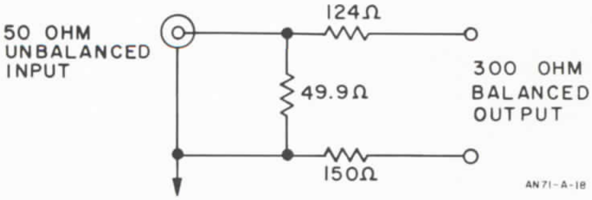



Figure 24. Typical pad for matching 50 ohm unbalanced generator output to 300 ohm balanced line. Loss is 6 db. (HP Model 508B).

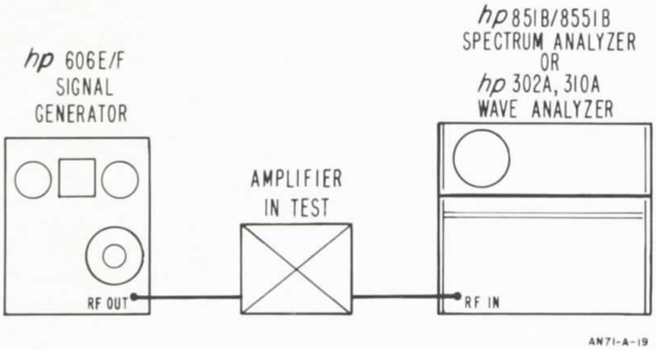


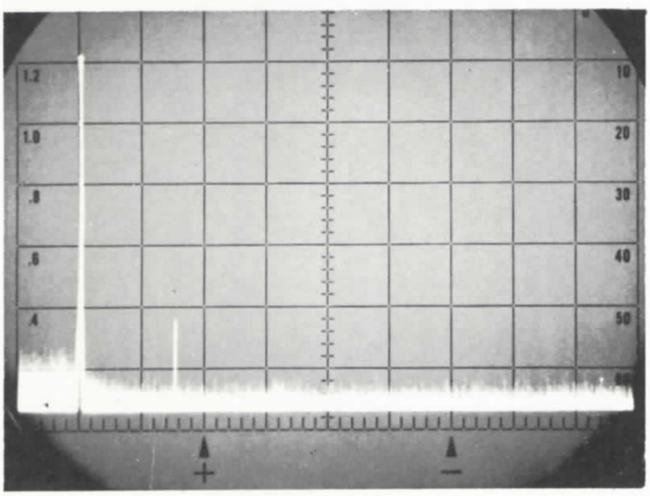

Figure 25. Amplifier distortion products above 10 Mc are measured with HP Spectrum Analyzer as shown. Harmonic content of HP 608E/F Signal Generator is greater than 35 db below carrier giving "clean" test signal to avoid error in amplifier distortion tests.

The spectral displays in Figure 27 show the output of a transistorized amplifier being driven by a 608E at 150 Mc. Photo (a) shows the result of overdriving the amplifier while (b) shows the normal distortion at 35 db down (<2%).

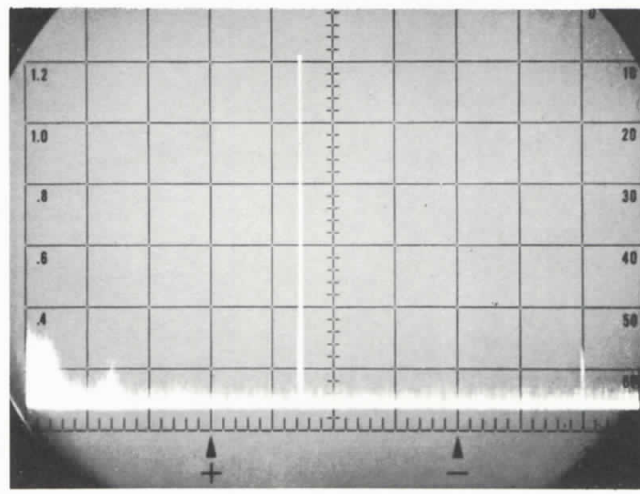
Harmonic content in the 606B and 608E/F varies with frequency and to some degree with each instrument. It is good practice to check the generator's harmonic content at the test frequency before connecting to an amplifier. In critical applications, selective filters can be used on the generator output to further reduce spurious signals.

**FILTER TESTING**

Those making filter response tests can really benefit from the frequency resolution and stability of the 606B and 608F/8708A.



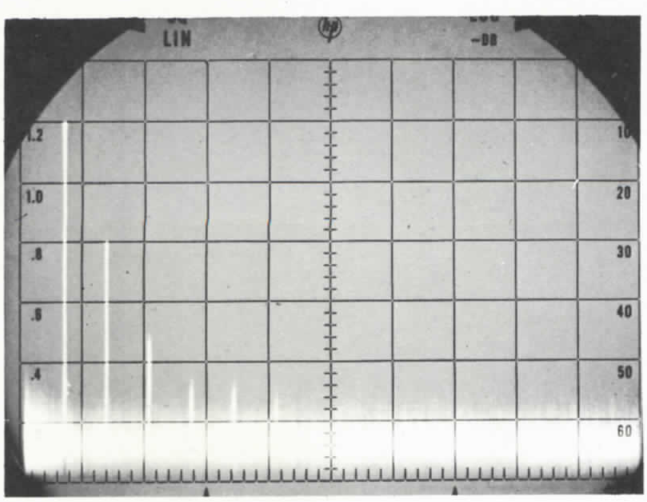
(a)



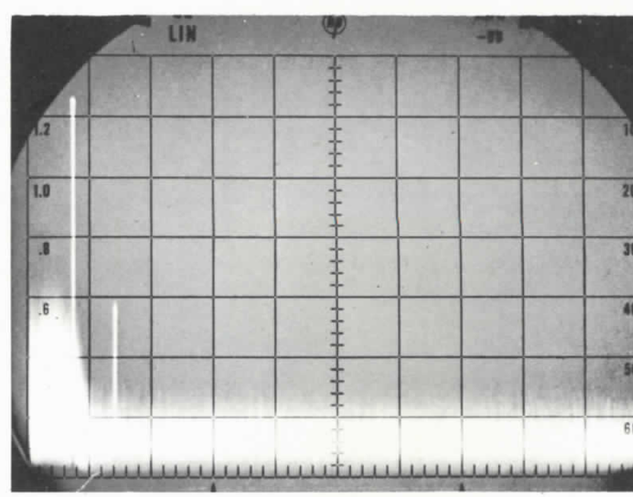
(b)

AN71-A-20

Figure 26. Low harmonic content in 608F output minimizes amplifier distortion test errors. Spectral displays show fundamental and harmonics of 608F at (a) 50 Mc and (b) 455 Mc. Vertical scale is 10 db/cm in both photos. Horizontal is 30 Mc/cm and 100 Mc/cm respectively.



(a)



(b)

AN71-A-21

Figure 27. Spectral displays show 150 Mc amplifier output and distortion products resulting from (a) overdriving input (b) normal input. Scales for both photos, 200 Mc/cm and 10 db/cm vertical.

Without the 8708A Synchronizer, the 606B $\Delta f$ control gives 1-2 cps frequency resolution at 455 kc, and 10-50 cps at 10.7 Mc.* When phase locked to the 8708A, 10 times more resolution is possible using the 8708A FREQUENCY TUNING control. With this resolution, even the sharpest cutoff characteristics of crystal or mechanical type filters can be plotted with precise point-to-point settings. Filters above the 606B frequency range can be checked with the 608F/8708A.

Skirt selectivity checks are more accurate when using a phase locked 606B or 608F because the test frequency is stable. Figure 28 shows the response of a mechanical filter designed for voice multiplex service.

When attempting transmission measurements on skirts this sharp, microphonics, residual FM or drift in the generator obscures the true filter attenuation. The filter output becomes some average level as the input frequency moves erratically about the desired point. With a phase locked 606B or 608F, these errors are removed.

Another advantage to this application is continuous tuning while phase locked. The desired frequency can be set exactly using a counter so continuous response curves can be made. This feature helps investigate the filters passband ripple.

High level output in both generators simplifies voltage readout of filters at high attenuations. The 606B provides 3 volts output (into 50 ohms) so filter attenuations greater than 70 db can be read on a standard hp 400 D/H AC VTVM.**

The new hp 3406A Broadband Sampling Voltmeter provides 1 mv readout sensitivity from 1 kc to 1 Gc for filter tests in either the 606B or 608F range.

## MORE APPLICATIONS - BETTER RESULTS

Many other applications will benefit from the new and improved features offered by the generators described here.

Attenuation tests benefit from leveled output because amplitude variations are removed.

Impedance, Q, and dielectric constant tests benefit from improved frequency stability and resolution.

The owner benefits from equipment versatility; both the 606B and 608F generators will phase lock with the 8708A. A counter can be added for high accuracy digital readout of frequency. Usefulness of these generators can be further extended by auxiliary instruments such as the Hewlett Packard Model 230A Power Amplifier. This amplifier increases the 608E/F output to 15 volts for high power applications such as RFI susceptibility and antenna work.

Both generators offer remote level control using a DC supply. The 606B requires 0 to -4.5 volts into 600 ohms to go from maximum RF output to minimum. The 608E/F requires 0 to -30 volts into 4K ohms for full range level control.

In nearly every application of HF-VHF signal generators there is a chance to get better data easier, faster and at lower cost. That's the job HP's new generators and synchronizer are designed to do. How about your application?

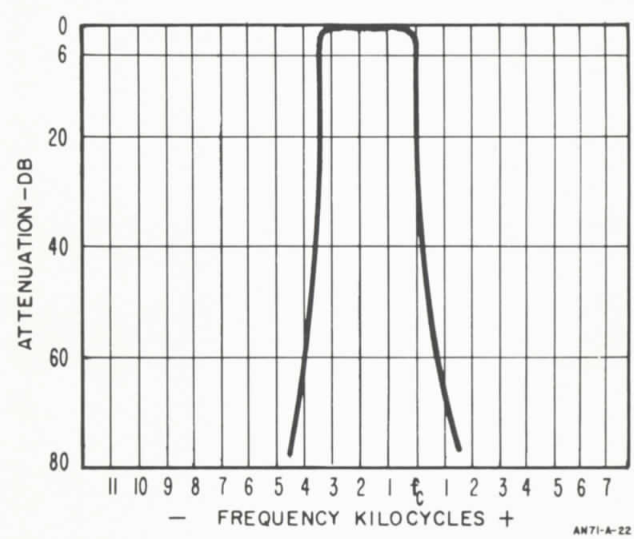



Figure 28. Passband of a mechanical filter used in receivers for sharp selectivity. HP 606B Generator and 8708A Synchronizer provide stability and tuning resolution required for fast accurate tests of such filters.

*455 kc and 10.7 Mc are typical receiver IF frequencies where filters are used for high selectivity.
**hp 400D/H frequency range 20 cps - 4 Mc.

# HEWLETT-PACKARD SALES AND SERVICE OFFICES

ALABAMA

**Huntsville, 35802**
2003 Byrd Spring Rd. S.W.
(205) 881-4591
TWX: 510-579-2204

ALASKA

**Bellevue, Wash. 98004**
11656 N.E. 8th Street
(206) 454-3971
TWX: 910-443-2303

ARIZONA

**Scottsdale, 85251**
3009 No. Scottsdale Rd.
(602) 945-7601
TWX: 602-949-0111

**Tucson, 85716**
232 So. Tucson Blvd.
(602) 623-2564
TWX: 602-792-2759

CALIFORNIA

**North Hollywood, 91604**
3939 Lankershim Blvd.
(213) 877-1282 and 766-3811
TWX: 910-499-2170

**Sacramento, 95821**
2591 Carlsbad Ave.
(916) 482-1463
TWX: 916-444-8683

**San Diego, 92106**
1055 Shafter Street
(714) 223-8103
TWX: 714-276-4263

**Palo Alto, 94303**
1101 Embarcadero Rd.
(415) 327-6500
TWX: 910-373-1280

COLORADO

**Englewood, 80110**
7965 East Prentice
(303) 771-3455
TWX: 303-771-3056

CONNECTICUT

**Middletown, 06458**
589 Saybrook Rd.
(203) 346-6611
TWX: 710-428-2036

FLORIDA

**Miami, 33125**
2907 Northwest 7th St.
(305) 635-6461

**Orlando, 32803**
621 Commonwealth Ave.
(305) 425-5541
TWX: 305-275-1234

**St. Petersburg, 33708**
410-150th Ave., Madeira Beach
(813) 391-0211
TWX: 813-391-0666

GEORGIA

**Atlanta, 30305**
3110 Maple Drive, N.E.
(404) 233-1141
TWX: 810-751-3283

HAWAII

**North Hollywood, Calif. 91604**
3939 Lankershim Blvd.
(213) 877-1282 and 766-3811
TWX: 910-499-2170

ILLINOIS

**Skokie, 60078**
5500 Howard Street
(312) 677-0400
TWX: 910-223-3613

INDIANA

**Indianapolis, 46205**
3919 Meadows Dr.
(317) 546-4891
TWX: 317-635-4300

LOUISIANA

**New Orleans**
(504) 522-4359

MARYLAND

**Baltimore, 21207**
6660 Security Blvd.
(301) 944-5400

**Rockville, 20852**
12303 Twinbrook Pkwy.
(301) 427-7560
TWX: 710-828-9684

MASSACHUSETTS

**Burlington, 01804**
Middlesex Turnpike
(617) 272-9000
TWX: 710-332-0382

MICHIGAN

**Southfield, 48076**
24315 Northwestern Hwy.
(313) 353-9100
TWX: 313-357-4425

MINNESOTA

**St. Paul, 55114**
2459 University Ave.
(612) 646-7881
TWX: 910-563-3734

MISSOURI

**Kansas City, 64131**
7916 Paseo Street
(816) 444-9494
TWX: 816-556-2423

**St. Louis, 63144**
2814 South Brentwood Blvd.
(314) 647-4350
TWX: 314-962-3933

NEW JERSEY

**Eatontown**
(201) 542-0852

**Englewood, 07631**
391 Grand Avenue
(201) 567-3933

NEW MEXICO

**Albuquerque, 87108**
6501 Lomas Blvd., N.E.
(505) 255-5586
TWX: 910-989-1655

**Las Cruces, 88001**
114 S. Water Street
(505) 526-2486
TWX: 505-524-2671

NEW YORK

**New York, 10021**
236 East 75th Street
(212) 879-2023
TWX: 710-581-4376

**Rochester, 14623**
39 Saginaw Drive
(716) 473-9500
TWX: 510-253-5981

**Poughkeepsie, 12601**
82 Washington Street
(914) 454-7330
TWX: 914-452-7425

**Syracuse, 13211**
5858 East Molloy Rd.
(315) 454-2486
TWX: 710-541-0482

**Endicott, 13764**
1219 Campville Rd.
(607) 754-0050
TWX: 510-252-0890

NORTH CAROLINA

**High Point, 27262**
1923 N. Main Street
(919) 882-6873
TWX: 510-926-1516

OHIO

**Cleveland, 44129**
5579 Pearl Road
(216) 884-9209
TWX: 216-888-0715

**Dayton, 45409**
1250 W. Dorothy Lane
(513) 298-0351
TWX: 513-944-0090

OKLAHOMA

**Oklahoma City**
(405) 235-7062

PENNSYLVANIA

**Camp Hill**
(717) 737-6791

**West Conshohocken, 19428**
144 Elizabeth Street
(215) 248-1600 and 828-6200
TWX: 215-828-3847

**Monroeville, 15146**
2545 Moss Side Blvd.
(412) 271-5227
TWX: 710-797-3650

TEXAS

**Dallas, 75209**
P.O. Box 7166, 3605 Inwood Rd.
(214) 357-1881 and 332-6667
TWX: 910-861-4081

**Houston, 77027**
P.O. Box 22813, 4242 Richmond Ave
(713) 667-2407
TWX: 713-571-1353

UTAH

**Salt Lake City, 84115**
1482 Major St.
(801) 486-8166
TWX: 801-521-2604

VIRGINIA

**Richmond, 23230**
2112 Spencer Road
(703) 282-5451
TWX: 710-956-0157

WASHINGTON

**Bellevue, 98004**
11656 N. E. 8th St.
(206) 454-3971
TWX: 910-443-2303

GOVERNMENT CONTRACTING OFFICES

**Middletown, Pa. 17057**
Hewlett-Packard
Contract Marketing Division
Olmsted Plaza
(717) 944-7401
TWX: 717-760-4816

**West Conshohocken, Pa. 19428**
Hewlett-Packard
Contract Marketing Division
144 Elizabeth Street
(215) 753-1811
TWX: 215-820-3847

CANADA

**Montreal, Quebec**
Hewlett-Packard (Canada) Ltd.
8270 Mayrand Street
(514) 735-2273
TWX: 610-421-3484

**Ottawa, Ontario**
Hewlett-Packard (Canada) Ltd.
1762 Carling Avenue
(613) 722-4223
TWX: 610-562-1952

**Toronto, Ontario**
Hewlett-Packard (Canada) Ltd.
1415 Lawrence Avenue West
(416) 249-9196
TWX: 610-492-2382

**Vancouver, B.C.**
Hewlett-Packard (Canada) Ltd.
2184 W. Broadway
(604) 738-7520
TWX: 610-922-5059

IN EUROPE

Hewlett-Packard, S. A.
54 Route des Acacias
Geneva, Switzerland
Telephone: (022) 42.81.50
Telex: 2.24.86
Cable: HEWPACKSA

IN LATIN AMERICA

Hewlett-Packard Inter-Americas
1501 Page Mill Road
Palo Alto, California 94304, U.S.A.
Telephone: (415) 326-7000
TWX: 910-373-1267
Telex: 033811 Cable: HEWPACK

ELSEWHERE

Hewlett-Packard
Overseas Sales Department
1501 Page Mill Road
Palo Alto, California 94304, U.S.A.
Telephone: (415) 326-7000
TWX: 910-373-1267
Telex: 033811 Cable: HEWPACK