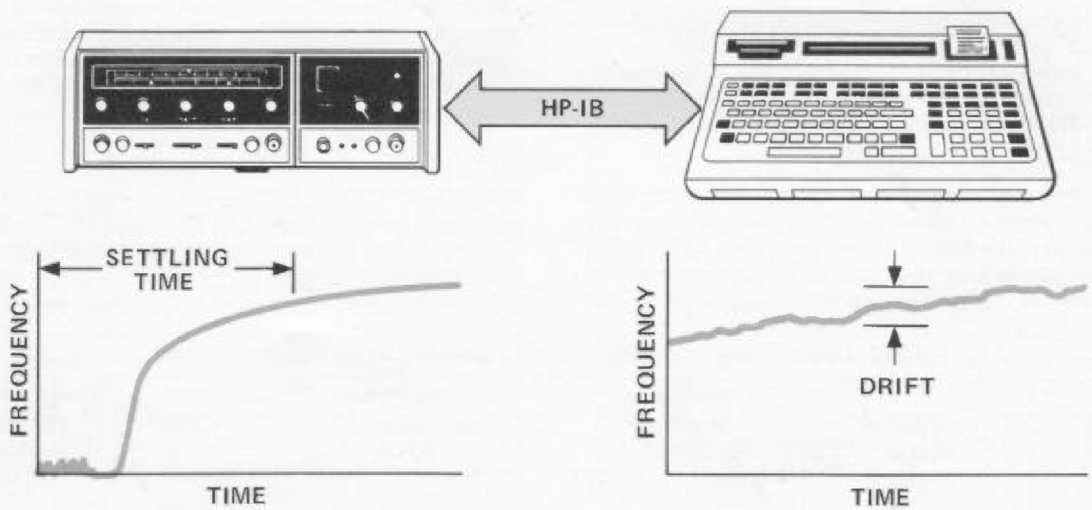
HEWLETT PACKARD
8620 SWEEP OSCILLATORS

The Frequency Performance of the 8620C Sweep Oscillator Under Remote Programming



The 8620C Sweep Oscillator in remote operation has distinct differences in performance over its manual use. For example, in bypassing the front panel controls and dial scale, the associated frequency errors are eliminated. However, data sheets and operating manuals typically specify manual performance only. Hence, remote operation characterization is necessary to optimize the selection of sweeper plug-ins for semi/full automatic test applications.

The purpose of this application note is to document the performance of the 86200 series plug-ins in remote programming operation. Techniques for increasing precision, reducing errors, and source calibration are described for hardware and software implementation. The intent is to provide the system designer with an enhanced measurement solution through plug-in performance optimization.

THE 8620C AS A PROGRAMMABLE SOURCE

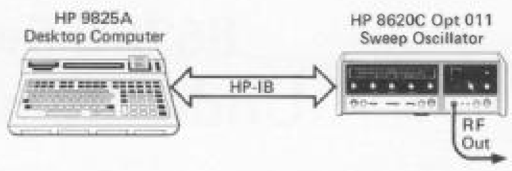
The 8620C Option 011 has the following modes of remote operation:

Digital Modes	- M1	Full Band
	M2	CW Delta F
	M4	Start/Stop Marker
Analog Sweep Modes	- M5	Full Band
	M6	CW Delta F
	M8	Start/Stop Marker
Analog CW Modes	- M3,	M7

Since the Analog Sweep and CW Modes function the same as in local operation, the specified manual performance and accuracies also apply to these remote modes. However, since the Digital Modes provide improvements in frequency performance, this note will reflect the 8620C in these remote operating modes only. Complete information on programming the 8620C Option 011 can be found in Application Note 187-5, "Calculator Control of the 8620C Sweep Oscillator using the Hewlett-Packard Interface Bus".

The most obvious advantage of remote operation is improved frequency accuracy. A major portion of a sweeper's frequency error is due to mechanical tolerances in the Marker pointers, dial scale divisions, and parallax. Elimination of the mechanical interface reduces the errors to those of the oscillator tuning circuitry.

Increased frequency resolution or settability is also possible under program control. When programming the 8620C Option 011, the Digital Modes provide a CW resolution of 10,000 points over the band or frequency range of interest. However, this frequency accuracy may be obscured by the voltage-to-frequency nonlinearities, tuning coil hysteresis, changes in load SWR, temperature, and time. These errors are minimized by following the calibration procedures for the mainframe HP-IB[1] Digital- to-Analog Converter (DAC) and the plug-in CW frequency accuracy in their respective Operating and Service Manuals. Further enhancement of the frequency accuracy can be implemented under program control if a frequency counter is available for periodic use. An "auto-calibration" routine and additional programming suggestions are discussed in a latter section of this note.



In making remote swept measurements, several characteristics of the source in addition to frequency accuracy are important. Frequency Repeatability is critical in accuracy enhancement applications where the calibration and test frequencies need to be close. The source settling time can limit the measurement cycle time. Table 1 summarizes the performance of 86200 series plug-ins in the above areas. In critical performance areas both typical and worst case values are indicated. The frequency accuracies correspond to programming in M1 mode only. If using M2 or M4 modes the accuracy is dependent upon the sweep width and will be between the values in Table 1 and the manual CW frequency accuracy specification.

Table 1. Performance of 86200 Series Plug-ins Under Programming[2]

Plug-in Model Number	Frequency Range (GHz)	Frequency Accuracy (MHz) Typical	Max	Frequency Repeatability (kHz) Typical	Max	Frequency Settling Time Typical (msec)	Freq. Drift w/Time (kHz/10 min) Typical after warmup of 1/2 hr	1 hr
86220A	0.01-1.3	± 7.5	± 9.5	± 400	± 1100	60	± 250	± 50
86222A/B	0.01-2.4	± 1.5	± 5.5	± 200	± 900	7	± 400	± 100
86230B	1.8-4.2	± 2.5	± 4.5	—	—	15	± 150	± 100
86235A	1.7-4.3	± 2.5	± 3.5	± 400	± 1300	15	± 150	± 100
86240A/B	2.0-8.4	± 3.5	± 8.5	± 200	± 700	10	± 450	± 150
86240C	3.6-8.6	± 3.5	± 8.5	± 200	± 700	10	± 450	± 150
86241A	3.2-6.5	± 10.5	± 23.5	± 200	± 600	10	± 300	± 200
86242C/D	5.9-9.0	± 5.5	± 15.5	± 300	± 2600	15	± 550	± 200
86245A	5.9-12.4	± 10.5	± 19.5	± 300	± 2000	15	± 650	± 200
86250C/D	8.0-12.4	± 8.5	± 24.5	± 800	± 1500	15	± 800	± 400
86260A	12.4-18.0	± 5.5	± 9.5	± 800	± 3000	5	± 550	± 450
86290A/B								
Band #1	2.0-6.2	± 2.5	± 3.5	± 100	± 300	5[3]	± 250	± 100
Band #2	6.0-12.4	± 2.5	± 4.5	± 200	± 500	5[3]	± 500	± 200
Band #3	12-18/18.6	± 3.5	± 8.5	± 300	± 900	5[3]	± 750	± 300

1. HP-IB is Hewlett-Packard's implementation of IEEE Standard 488 and identical ANSI Standard MC 1. 1 "Digital interface for programmable instrumentation." Internationally, HP-IB is in concert with the IEC main interface document.
2. These Performance Characteristics are intended to provide information useful in applying the instrument by giving typical, but non-warranted, performance parameters.
3. Approximately 6 msec should be added if switching from one band to another.

Test Conditions

The above performance characteristics are representative of the 8620C/86200 series plug-in under a lab type environment. The instruments tested were stacked, with proper ventilation, at a controlled temperature (approx. 25°C), and allowed a one hour warmup period. Each source was calibrated after the warmup period to the greatest accuracy obtainable for the 8620C Option 011 DAC and the plug-in CW frequency accuracy. These conditions are recommended for any system, especially automatic, so that the accuracy, repeatability, and settling time are representative of a stable source. Note that the plug-ins were tested at their maximum leveled power, internally leveled, and with the FM/NORM/PL mode switch in the FM position. Also, the 8620C was switched to AUTO Sweep mode. The importance of these conditions are discussed later in this note.

Frequency Accuracy is the correlation between the frequency expected at the calculated tuning voltage and the actual frequency. Frequency Repeatability indicates the deviations in frequency at a specific tuning voltage that are encountered in digital sweeps and random CW programming. The repeatability data was taken from numerous sweeps in one-hour periods with the frequency deviations incurred from the respective initial sweep frequencies. The effects of drift with time could not be extracted from the measurements, but the source was very stable after 15 minutes of sweeping. For both accuracy and repeatability a normal distribution of test values was detected. From this the typical values represent one standard deviation distribution containing 68.3% of the results. The maximum values represent 3 standard deviations and 99.7% of the values. The frequency settling time is the typical time for the source to be within 1 MHz of its final value; less time is needed to reach the CW frequency accuracy value. The frequency drift with time is the typical worst case drift per 10 minute interval after the half- and one-hour warmup periods.

Some Considerations

As previously mentioned, the 8620C Option 011 provides a 10 volt tuning range (0-10V) and 10,000 point resolution for every plug-in band. Normally the plug-in's specified frequency range is controlled by the entire 10 volt tuning range, but due to the nature of their design some are not. The designer must be aware of the actual and specific frequency ranges and their respective tuning voltage ranges. Most notable here are:

1. 86220A 0.01-1.3 GHz Heterodyne Plug-in		
specified frequency range:	0.01 - 1.3	GHz
tuning range:	0.077 - 10.0	Volts
2. 86241A 3.2-6.5 GHz Plug-in		
actual frequency range:	3.1 - 6.6	GHz
tuning range:	0.0 - 10.0	Volts
specified frequency range:	3.2 - 6.5	GHz
tuning range:	0.286 - 9.714	Volts
3. 86260A 12.4-18.0 GHz Plug-in		
actual frequency range:	12.0 - 18.0	GHz
tuning range:	0.0 - 10.0	Volts
specified frequency range:	12.4 - 18.0	GHz
tuning range:	0.667 - 10.0	Volts

For the above, performance is not warranted in the non-specified frequency areas, so using the proper frequency endpoint tuning voltages or frequencies will yield the best performance.

The status of the plug-in FM mode switch (FM/NORM/PL) and the 8620C sweep mode (AUTO/EXT/MANUAL) will affect CW performance in the remote digital modes (M1: Full Sweep, M2: CW Delta F, and M4: Marker Sweep). These two functions will determine whether a large capacitor is switched into the tuning coil circuit. The capacitor will reduce the Residual FM but also lengthen the settling time. For many applications, minimum tuning hysteresis and maximum speed are important so the capacitor is undesirable. To disable the capacitor there are two solutions:

1. The plug-in FM switch is in FM or PL

   or

2. The plug-in FM switch is in NORM and the 8620C sweep mode switch is in AUTO or EXT.

Note that if the capacitor is disabled the Residual FM will increase by a factor of 2 to 4 and settling times will decrease by a factor of 3 to 4 (plug-in dependent). If longer settling times are not critical and Residual FM is, then the capacitor should be enabled by setting the plug-in FM switch to NORM and the 8620C sweep mode to MANUAL[4].

FOR ADDITIONAL PRECISION

For systems that require an accurate, repeatable, and stable source, the 86222A/B and 86290A/B plug-ins perform exceptionally over their broadband range. Their performance is critical, for instance, in HP 8409A Semi-Automatic Network Analyzer measurements (see Application Note 221, "Semi-Automatic Measurements Using the 8410B Microwave Network Analyzer . . . "). Specifically, their source accuracy and repeatability are essential when testing devices of long electrical length and/or large slope. For example, in testing a 10 meter polyethylene coaxial cable over 12-18 GHz, the 86290 (Band 3) repeatability translates into a phase uncertainty of approximately ±5.4°, whereas the 86260A (12.4-18 GHz) repeatability results in an uncertainty of ±14.4°.

Improved Programming Techniques

As all 86200 series plug-ins require a specific **warmup period,** it is a simple program addition to allow a one hour warmup at the system turn-on. The sweeper will attain optimum stability and accuracy if warmed up in one of the two following modes. (1) Manually set the Start/Stop Markers at the endpoints of the frequency range of interest and program the analog M8 Marker Sweep mode. The sweeper will sweep the intended frequency range allowing the oscillator to reach thermal equilibrium. Or (2) Warmup at a CW frequency yielding a thermal equilibrium approximately that of sweeping. The basis for these warmup modes is due to the oscillator tuning structure, the heat dissipated by the oscillator will differ greatly between the two band endpoints. Using the CW frequency equal to the midpoint of the marker sweep is a good approximation for the average power dissipated.

Environmental temperature changes will significantly alter the frequency stability. A temperature variation of several degrees Celsius can cause frequency errors greater than the CW accuracy (<±5.4 MHz/°C in 86260A). Solutions call for controlling the temperature or recalibrating the CW accuracy at required intervals. The latter can be

4. Further information on the affects of the CW filter capacitor in the 8620C can be found in the 8620C Operating and Service Manual dated after September 1978.

implemented via program routines and a frequency counter with either a manual plug-in readjustment or program constant updating of the frequency band endpoints. This simple "auto-calibration" routine uses the measured frequency band endpoint frequencies and specified tuning voltages for a more accurate frequency/tuning voltage calculation.

Since swept measurements are accomplished with a rapid succession of CW measurements, **oscillator hysteresis** effects can be encountered. Several approaches are available to reduce the errors in accuracy and repeatability. In general, it is best to adhere to one direction of sweeping, preferably up the band of interest. This consistency will maintain frequency offsets of similar polarity and magnitude. A somewhat more time consuming method is to program each frequency after resting momentarily at the lowest frequency of interest. By returning to the low point, the up/down programming tends to reduce the hysteresis overshoot.

The measurement system may be affected by the **settling time** of its source. Most 86200 series plug-ins reach a value well within their CW accuracy in less than 15 msec after commanding the sweeper. The system program should allow these periods to achieve required accuracy and yield valid measurements. Those affected most are frequency counters and instruments utilizing a technique locking to the source (eg. 8410B). The worst case effects occur when switching from low to high band endpoints (or vice-versa), so adding wait states or a second measurement initiation cycle may be required to minimize the effect.

Accuracy Enhancement Schemes

For frequency accuracy requirements that exceed a plug-in's performance, several schemes can be implemented for an improved measurement system. Each of the following test systems extend the precision of the sweeper with varying degrees of complexity and performance. All of the following systems are compatible with the HP 8410B Microwave Network Analyzer when the 8620C/8410B source control cable is used.

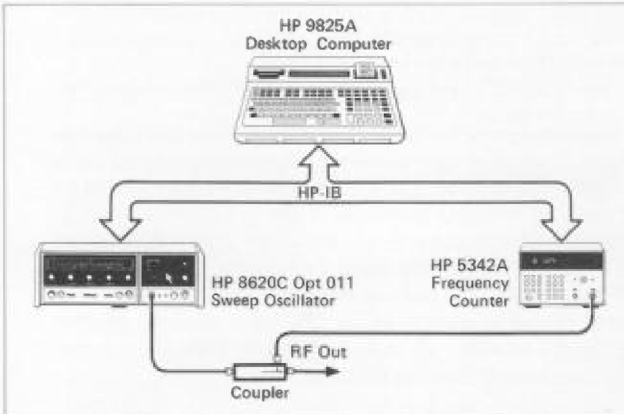
Auto-Calibration Routine

To compensate for CW frequency drift with time and temperature, an automatic frequency recalibration routine can be used. By accurately knowing the band low and high frequencies the frequency accuracy improves. This routine uses the proper endpoint tuning voltages (as previously mentioned) for each band of the plug-in tested. The frequency counter used can be dedicated to the system or periodically hooked up and shared with other test stations. The routine operates by:

1. Programming the sweeper to the band low frequency
2. Reading the frequency after a sufficient settling time
3. Programming the sweeper to the band high frequency
4. Reading the frequency after a sufficient settling time
5. Updating the program band endpoint frequency constants with the two readings
6. Iterating steps 1 thru 5 for each plug-in band

This automatic routine allows source recalibration at any point in time. Recalibration is most effective in the lower frequency bands, particularly those covered by the 86220 and 86222. Another feature that can be included is to notify the operator that manual recalibration is necessary when a frequency exceeds a particular deviation. There are three plug-ins (86242, 86245, and 86250) that require 3 CW frequency accuracy adjustments (low, mid, high) versus the normal 2. Manual calibration is more critical in these plug-ins as relying on the two frequency band endpoints could result in midband tuning nonlinearities. You may wish to modify the routine to calibrate at the 25 and 75% frequency points of the band or divide the band in half and use the routine for each section.

The Counter Feedback System

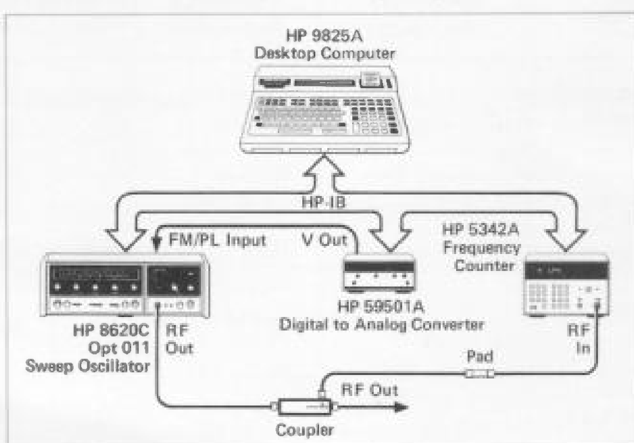


Dedicating a microwave frequency counter to the system allows frequencies to be set to a resolution of ±0.005% of the plug-in bandwidth (<±350 kHz in the 12-18 GHz band of 86290). However, due to a random bit error of the DAC the accuracy may be reduced to ±0.015% of the bandwidth. The Counter Feedback Loop described in Application Note 187-5 is used such that each frequency is set by:

1. Calculating the proper tuning voltage
2. Programming the sweeper
3. Sampling the frequency with counter
4. Calculating new tuning voltage from the frequency offset
5. Reprogramming the sweeper

Iterating steps 3-5 allows the loop to achieve optimum accuracy in typically 1 to 2 iterations. The best performance occurs with the frequency band endpoints properly calibrated so loop iterations and time are reduced. Band recalibration ("auto-calibration") is a simple program addition and may be utilized as necessary.

Automatic Frequency Control (AFC)



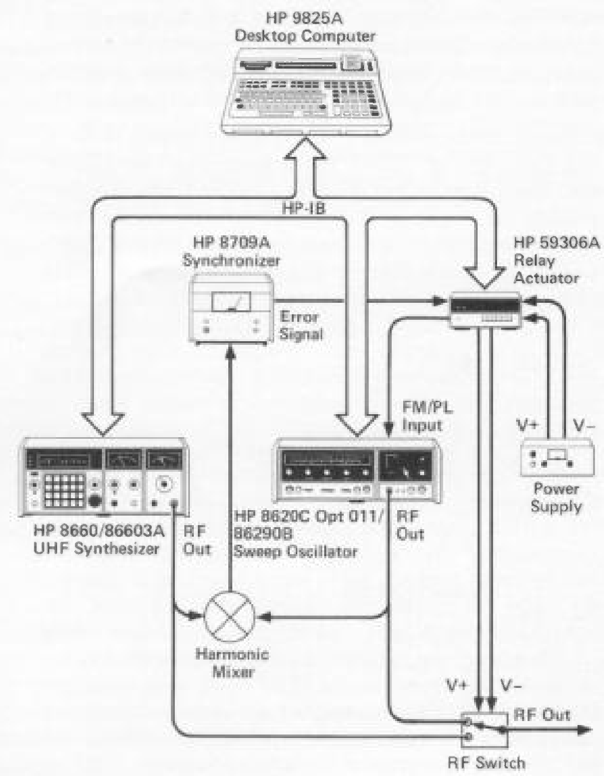
An extension of the counter feedback loop, AFC provides the optimum frequency resolution of a plug-in. Physically limited by its Residual FM (<30 kHz peak worst case, with the CW capacitor), use is made of the FM capability to provide small frequency offsets in addition to the sweeper tuning voltage. A programmable DAC is used to drive the plug-in's External FM input with maximum frequency excursions of ±15 MHz to ±150 MHz (set by plug-in specification). The plug-in is operated in either FM or Phase-Lock (PL) mode, which will determine the sensitivity of the External FM input. Typical sensitivities are −20 MHz/Volt for FM, −6 MHz/Volt for PL. Now each frequency is set via:

1. Coarse set by programming the sweeper
2. Medium set by counter feedback loop
3. Fine set by DAC at proper voltage to shift the frequency

Once again iterating both feedback loops provides the optimum accuracy but also increases the measurement time per point. Variations of this scheme allow the use of either or both tuning voltages (sweeper, External FM) to provide the required time/accuracy relationship. Auto-calibration routines for the frequency band endpoints and the External FM sensitivity will reduce the feedback loop time and iterations per frequency point. A comparison of the measurement speeds of this technique and others are made in the table following this section.

Frequency Synthesizer Phase Lock

The best frequency accuracy occurs when the source is phase locked to a synthesized reference oscillator. One system is described in Application Note 187-2, "Configuration of a 2 to 18.6 GHz Synthesized Source . . .", where the sweeper stability and accuracy is that of a UHF Synthesizer. This results by programming the sweeper to the desired frequency and the synthesizer to a subharmonic. The two signals are mixed down and synchronized to a fixed IF. The instruments involved are a UHF Synthesizer (HP 8660/86603A 1-2600 MHz), harmonic mixer, Synchronizer (HP 8709A), controller, and sweeper (8620C/86290B). With the addition of an RF switch, a 1 MHz to 18.6 GHz "synthesized" source is available by using the synthesizer 1 MHz to 2.6 GHz and the locked sweeper 2.6 to 18.6 GHz. Overall, the typical accuracy and stability is <±54 Hz/day at 18 GHz, resolution 15 Hz, and settling time 100 msec for 1 kHz accuracy.



Unlike a dedicated synthesizer, this approach allows the source to be analog swept when not locked (requires disabling the 8709A error signal). This is useful, for example, to tune up the device under test and/or the Network Analyzer across the frequency range of interest before the digitally swept response data is taken. Overall, this system allows the upgrading of present equipment into a phase-locked sweeper with synthesizer-like performance.

Table 2. Comparison of 2-18 GHz HP-IB Test Systems

Scheme	Frequency Accuracy	Frequency Resolution	Frequency Repeatability	Freq. Drift W/Time	Settling Time/Pt.	Instruments Used
Stand Alone Sweeper	see plug-in data in Table 1					8620C/86290
Counter Feedback	< ±0.015% BW	< ±0.005% BW	see plug-in		≈110 msec/iter.[5]	8620C/86290 5340A or 5342A
AFC	Residual FM of plug-in			see plug-in	≈115 msec/iter.[5]	8620C/86290 5340A or 5342A 59501A or 59303A
Phase-lock (AN187-2)	3×10^{-9}/24 hr (< ±54 Hz/day @ 18 GHz)	≈15 Hz	≈15 Hz	3×10^{-9}/24 hr (< ±54 Hz/day @ 18 GHz)	≈100 msec/pt.	8620C/86290 8660/86603A 8709A, etc.

5. Using the 5342A in Manual mode.

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