Agilent 8645 Signal Generator Communication

Product Note 8645-2

Agilent Technologies

A catalog of 8645A information

This product note is actually a compilation of many brief product notes, each concerned with a particular aspect of the 8645A agile signal generator. Included in these pages are explanations of how this unique signal generator operates, the capabilities it has to offer and the performance it can provide. The objective of this product note is to be a reference guide for the owner of a 8645A, to help maximize the usefulness and performance of this agile signal generator in the intended application. While none of the topics are covered in great detail and other literature may offer a more thorough treatment of a subject, these summaries should provide sufficient information to help in many situations.

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Operation related topics

Block diagram and theory of operation

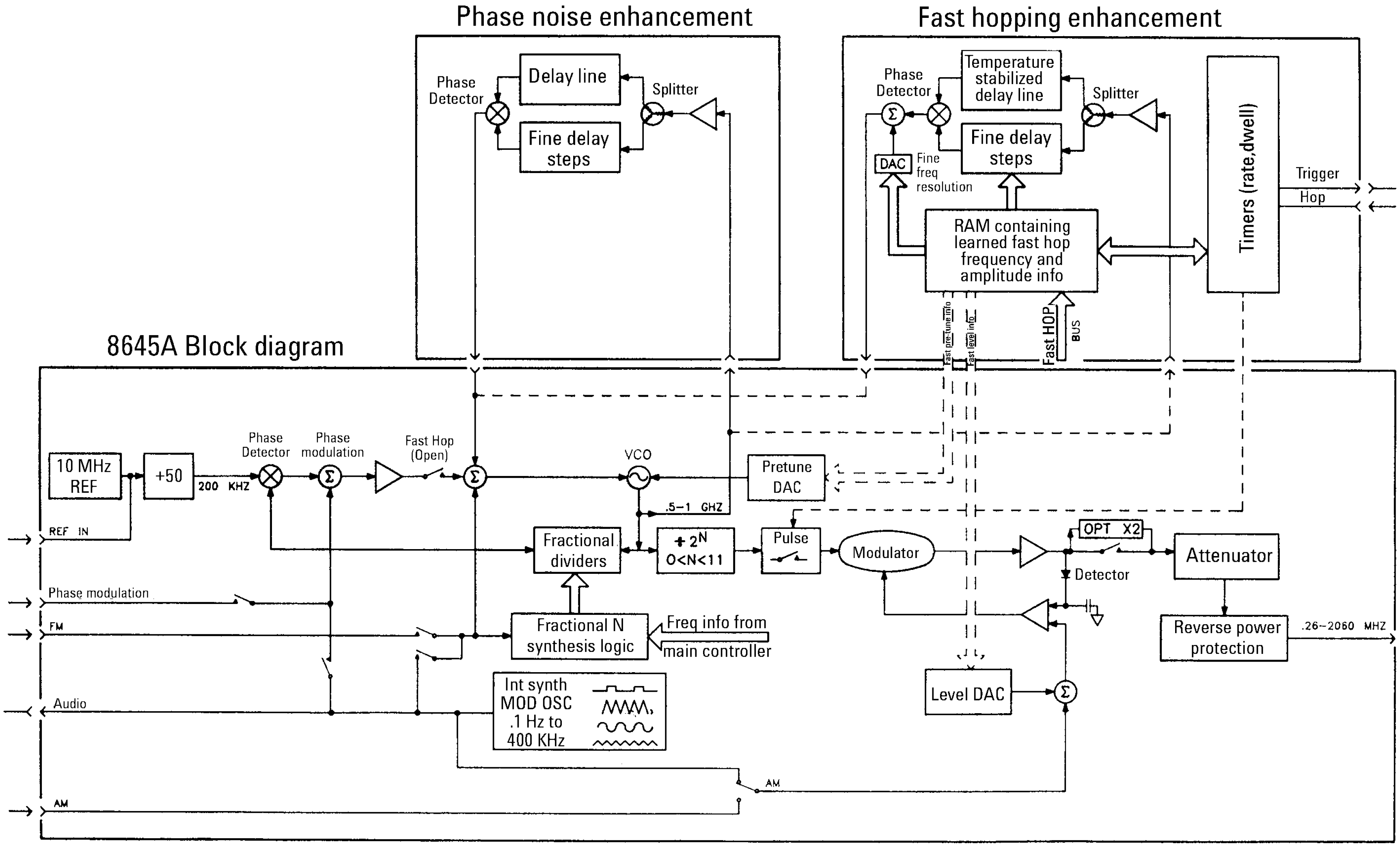
The basis of the 8645A is a single fractional N loop controlling a VCO operating in the frequency range of 515 to 1030 MHz. The reference signal for this phase lock loop originates from either an internal 10 MHz oscillator or an external input. An extensive divider section at the output of the phase lock loop provides coverage down to 252 kHz and a doubler in the output section extends the frequency range to 2060 MHz. All four modulation types are implemented in the 8645A with either the internal 400 kHz synthesizer integrated circuit providing the modulation waveform or an external input. Frequency modulation uses two techniques including an analog signal summed into the VCO tuning input and a digitized FM technique that directly modifies the fractional N number of the phase lock loop. Phase modulation signals are summed directly into the fractional N phase lock loop. Pulse modulation occurs directly after the divider section. Amplitude modulation is accomplished in the output section through control of the Automatic Level Control (ALC). The AM signal is summed together with the level DAC which sets the amplitude level that reaches the attenuators. The combination of the level DAC, the AM signal, and the attenuators (up to 120 dB of attenuation) determine the actual output level of the 8645A. The Reverse Power Protection (RPP) prevents the output circuits from damaging signals externally input through the generator's output. Controlling all of this hardware in the many states the user can set up is a Motorola 68000 microprocessor.

The basic block diagram summarized above produces all the traditional functions of a signal generator. For the applications intended for the 8645A, the phase noise and spurious signals must be very low at offsets greater than approximately 10 kHz. A major advantage of the block diagram is that a clean-up loop based on a delay line and a phase detector can be added in parallel to the fractional N phase lock loop. The 70 nsec delay line in the clean-up loop of the phase noise enhancement section decreases the phase noise and spurious signals to levels required by communications hardware tests.

Besides high performance outputs for traditional applications, the 8645A is designed to provide sequences of many frequencies in rapid order. Frequency switching is specified as fast as 15 usec between frequencies. To accomplish this switching speed, the fractional N phase lock loop is opened and replaced by a delay line frequency lock loop. Phase noise and spurious signals on the VCO output are again decreased by the delay line and phase detector in the fast hop enhancement section. VCO settings learned before fast hop operation begins are sent to the VCO through a pretune DAC in the order of the output frequencies the user wants and at the rate programmed. Amplitude information is simultaneously sent to the level DAC. A hardware state machine programmed by the microprocessor provides all the fast control signals needed while fast hop operation is underway.

Many of the operational areas briefly discussed on this page are covered more thoroughly in other parts of this product note. Refer to the table of contents for a listing of the topics.

8645A Block diagram



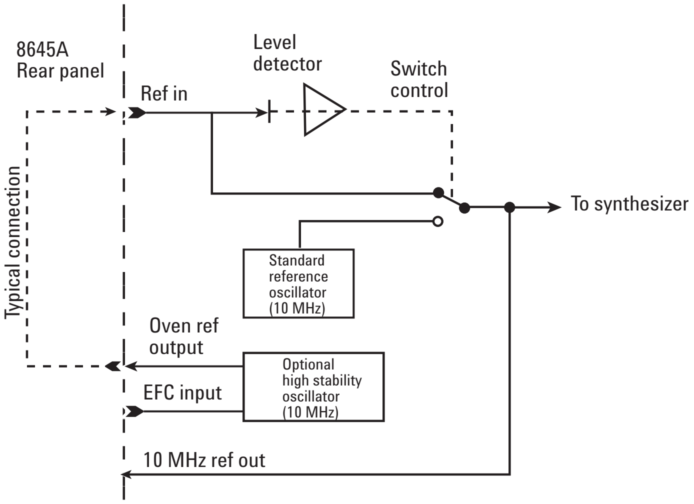
Timebase configurations

The frequency stability of the 8645A depends a great deal on the reference oscillator in use. The standard internal timebase is a non-ovenized 10 MHz crystal oscillator with a typical aging rate of ±2 ppm per year. With this timebase, a 1 GHz output of the signal generator would not vary more than ±2 kHz in a year due to timebase aging. However, the frequency drift due to temperature changes may be twice this amount because this oscillator is not ovenized. Although the 8645A has several design features to minimize internal temperature fluctuations, the standard timebase could drift by as much as ±4 ppm over a temperature range variation of 0 to +55 degrees centigrade.

Option 001 of the 8645A adds a more stable 10 MHz ovenized timebase to the instrument. The aging rate is specified to be better +0.0005 ppm or a 0.5 Hz variation of a 1 GHz output in 24 hours after a 10 day warm-up. Frequency drift due to a ambient temperature change of 0 to +55 degrees centigrade is typically less than +0.006 ppm. The frequency of this timebase can be mechanically adjusted through a hole in the rear panel using a tweaker. Voltage control of the timebase frequency is available using the Electronic Frequency Control (EFC) input. The maximum ±10 volt EFC input signal will produce a ±1 Hz frequency change of the 10 MHz output.

The output of this optional high stability timebase is only routed to the rear panel of the instrument as the **oven ref** output. An external jumper cable is used to input this reference signal at the **ref in** port for routing into the frequency synthesis circuits. When this jumper cable is connected, the instrument will sense the presence of a reference signal at the **ref in** input and utilize it automatically. Without a signal present at the **ref in** input, the 8645A will use the standard timebase as its reference oscillator.

To allow other instruments to use the timebase signal from the 8645A, the rear panel 10 MHz **ref out** output provides an output of either the standard or optional timebase that is currently in use. The signal generator can also utilize an external 10 MHz timebase that would be input at the ref in input. Activating special function 161 will provide a readout indicting whether the 8645A is utilizing the standard timebase or a signal entering the **ref in** input.



8645A internal timebase configuration

Internal audio source

The internal audio source in the 8645A can generate four basic waveforms of sine, sawtooth, square, and white Gaussian noise. Waveforms are generated by a numerical synthesis technique. The heart of the synthesizer is a Digital Waveform Synthesis Integrated Circuit (DWSIC). The DWSIC generates a continuous stream of numbers that represents instantaneous levels of the waveform. This “digital” waveform is then converted to an analog signal by a digital-to-analog converter. The analog signal is conditioned by conventional analog circuitry and routed to various parts of the signal generator. The conditioning circuits include a sample and hold to remove DAC switching noise, filters to remove quantization noise, and amplifiers to boost the output.

The internal audio source is used in the signal generator for modulation, sweeping, calibration, and diagnostics. To the user, the source appears like an internal function generator used to modulate the carrier with the four basic waveforms. It is also used as a ramp voltage into the FM circuitry during phase continuous sweep that disallows internal modulation being active this sweep mode. This source is used as an accurate DC reference to calibrate FM deviation and AM depth when these modulations are active. The built-in diagnostics use the source for DC and AC signals to test various modules in the instrument. And of course the audio signal is available at the front panel audio output with programmable waveforms, amplitude, and frequency.

The type of waveform produced can be selected by activating special function 130 or via GPIB with the command LFS:Waveform <type> where <type> is sin, square, saw, or WGN (for white Gaussian noise). The frequency can be selected over a range of 0.1 Hz to 400 kHz. Sawtooth and squarewave rates should be limited to less than 50 kHz because the output circuitry degrades the performance at higher rates. Frequency accuracy is equal to the internal timebase accuracy of the instrument. Frequency switching speed of the source is typically less than 30 msec. Output level is programmable and ranges from 1 mV to 1 Vrms into a 600 ohm load with a specified accuracy of ±20 mV. Adjusting the output level will effect the amount of internal modulation present such that a decrease in output level will proportionately decrease the amount of internal modulation. This feature can be used to increase the amount of external modulation allowed during simultaneous internal and external modulation. The sum of the internal and external voltages should not exceed 1.4 Vpeak during simultaneous modulation or clipping distortion may occur.

Frequency sweep capabilities

The 8645A was designed to have three different types of frequency sweep operation to accommodate a wide variety of applications. As is evident from the descriptions that follow, the wide deviation FM capabilities and the fast hop operation offer unique sweep capabilities not present in the typical RF signal generator.

The most useful sweep for finding the frequency response of narrowband devices is the phase continuous frequency sweep. The instrument uses the wide deviation FM circuitry to create a phase-continuous output over spans as wide as twice the maximum FM deviation available for that carrier frequency range. In the main VCO band of 515 to 1030 MHz the maximum span is 20 MHz. This range is decreased by half for each divider band below this main carrier band. A sweeptime range of 10 msec to 10 seconds is allowed for any span that is chosen. Only a linear frequency sweep is allowed. Another capability that offers very high accuracy of each frequency point of the sweep is the digitally stepped frequency sweep. The instrument will step the synthesizer across any span set by the user in a linear or log frequency spacing. The number of discrete points output will depend on the span and sweeptime that is set. Sweeptime can range from 0.5 to 1000 seconds with each discrete point requiring typically 90 msec to complete. To reduce the amount of switching transients spurs due to each frequency change, the output level is reduced approximately 60 dB between each discrete frequency. This amplitude blanking may cause dropouts on the displayed frequency response. Due to these dropouts it may be more useful to specify a fast hop sweep for wide frequency spans as the following describes.

A unique frequency sweep capability of the 8645A is the fast hop sweep. Utilizing the frequency agile capability, large frequency spans with 1000 discrete frequency steps in as little as 100 msec per sweep. The number of frequency steps varies according to the sweeptime and frequency range selected with each discrete step taking 30 microseconds for outputs from 128 to 2060 MHz. The user can set a sweeptime range from 10 msec to 100 seconds. Although the output is blanked between each frequency step as in digitally stepped sweep, the duration of the blanking is so short that the detector used to measure the frequency response will typically not show the dropout on the oscilloscope or network analyzer. Either a linear and log distribution of frequency steps can be selected.

Each of the three types of frequency sweep described above can be operated in a continuous repetitive output or a single sweep output triggered by the press of a key or an HP-SL command. Additionally the digitally stepped and fast hop sweep types can be operated manually using the front panel knob or up/down arrow keys. Up to three markers can be entered for output during a sweep. When the sweep reaches the marker frequency a 0 volt signal is output from the Z axis port on the rear panel. The Z axis output is +1 volt during a sweep and +5 volts during retrace to blank the CRT of an oscilloscope. The X axis output of 0 to 10 volts matched to the progress of the frequency sweep.

Externally doubled outputs to 2060 MHz

For applications requiring outputs above the 1030 MHz maximum frequency of the standard 8645A, consideration can be given to either ordering the 8645A with the optional internal doubler, installing the 11867A retrofit kit or using an external doubler. This technical brief summarizes the capabilities and performance the user can expect while using one such external doubler, the 11721A frequency doubler, to increase the frequency range of the 8645A to 2060 MHz. The 11721A frequency doubler is a passive, full-wave rectifying doubling circuit that was designed to minimize conversion loss over a wide frequency range. Its output frequency range is 10 MHz to 2560 MHz. At input levels above +13 dBm the doubler has an almost constant conversion loss of approximately 11 dB. This typical conversion loss after the +16 to +18 dBm maximum output of the 8645A results in an output signal level of +5 to +7 dBm for the average 11721A external doubler. The harmonic and spurious content of the output is almost completely a function of the input signal. Note that harmonics input to doubler (specified at <–30 dBc for the 8645A below 1030 MHz) will increase approximately 6 dB due to the doubling function. The same 6 dB increase will be present on the phase noise of the carrier. Any frequency modulation at the input to the doubler will double in deviation also.

For frequency agile signals, the 11721A has no measurable affect on the frequency switching time up to the fastest time of 15 usec available on the 8645A.

By using special function 111 frequency multiplier with an entered multiplier of 2, the display of the 8645A will represent the signal at the output of the doubler as a convenience. Simultaneously, the doubler's conversion loss can be entered as an amplitude offset to calibrate the display for the actual amplitude at the doubler's output.

More general information about the 11721A frequency doubler in use with the 8662A synthesized signal generator is available in application note 283-2 (literature number 5952-8217).

Operation as a phase noise measurement reference

Among several techniques for measuring the phase noise of a source is the method of using a second source to demodulate the phase instability using a phase detector. Commonly referred to as the phase detector method, this process requires that the second source or reference source have as good or better phase noise performance than the source being tested. It is also required that one of the sources have an FM capability in order to maintain phase quadrature at the output of the phase detector. These needs for good phase noise performance and FM capability often result in a generic signal generator being used as the reference source of a phase noise measurement system. The subject of this brief product note is how to optimize use of the 8645A as a reference source for phase noise measurements. More information on the measurement technique itself can be found in literature related to products such as the 11729C carrier noise test set or 3048A phase noise measurement system.

Several features of the 8645A make it a good choice for use as a phase noise measurement source. These include the wide carrier frequency range, an output power of +16 dBm and a large FM deviation range. The phase noise of the 8645A's output is very low at offsets greater than 10 kHz from the carrier, as is commonly required for testing channelized communication devices or systems. The 8645A has very few spurs on its output which simplifies the detection and interpretation of spurs from the test source. The typical phase noise and spurious performance is indicated in the graph included in the "phase noise performance" summary of this product note.

As with any reference source used in the phase detector method, only as much FM deviation as required to establish the phase lock loop for the measurement should be used. Minimizing the FM deviation decreases the noise contribution of the FM circuits and reduces the potential for an unstable Phase Lock Loop (PLL). The design of the 8645A uses two different FM implementations that the user should choose between according to the FM deviation range required. The standard FM is recommended for phase noise measurements that use a PLL bandwidth of less than 1.6 kHz. Variations in the group delay of the FM circuits for deviation settings to support more than 1.6 kHz could cause inaccurate measurements or loop oscillations. For situations that require more loop bandwidth, it is recommended that the fast hop mode be activated for the measurement. In the fast hop mode the group delay of the FM is very low and remains constant at higher FM deviations. Although the phase noise at low offsets increases in this mode, it is generally acceptable as sources that require more FM range to maintain quadrature also have higher phase noise to be measured.

One other unique characteristic of the 8645A is that several circuits internally are reset whenever the center frequency setting is changed so the output is not phase continuous during these changes. The output is decreased by more than 60 dB during these resets so that the unspecified output during the transition will not affect the user's device. This transition period lasts less than 85 msec typically. While this operational characteristic will not affect a phase noise measurement in progress, it will be apparent when the center frequency of the 8645A is being tuned as the beatnote disappears momentarily with each change. This signal interruption will cause the PLL to momentarily break lock. Activating special function 105 amplitude muting disables this amplitude blanking but the unspecified transitions of the output signal could still result in perturbations while tuning frequency.

Programming with HP-SL

Hewlett-Packard Systems Language (HP-SL) is the programming language for instrumentation adopted by Agilent Technologies. This language uses standard GPIB hardware and will be used in many new Agilent products. The 8645A is the first signal generator to implement HP-SL. HP-SL uses self-explanatory commands and is flexible for beginning and advanced programmers. Programs written in HP-SL for the 8645A will be compatible with the other generators with the exception of commands associated with unique functions of the signal generator such as fast hop capabilities. This is intended to minimize software modifications by the customer when hardware is upgraded or replaced.

Many Agilent divisions have contributed to the development of HP-SL and will use it as part of an interface system that conforms to the new IEEE 488.2 standard. The advantage of the new IEEE standard is that it defines common global commands such as for the instrument preset function, as well as hardware and protocol that is compatible with previous standards. In the short term HP-SL will be easier to learn and self documenting and in the long term, HP-SL will provide a more common language to reduce the cost of software support.
A simple example shows how HP-SL commands are self explanatory and what a typical program for the 8645A could look like. The following program lines will perform an instrument preset on the signal generator, set the RF frequency to 500 MHz and the amplitude to 10 dBm, and turn the RF output on.

```
100  Output  719;  “*RST”
200  Output  719;  “Frequency:CW 500 MHz”
300  Output  719;  “Amplitude:Level 10 dBm”
400  Output  719;  “Amplitude:State on”
```

This example programming can be further simplified because with HP-SL commands can be combined in a single output statement without regard for the order in which the instrument will execute the commands. This means that HP-SL instruments will take in the full command “message” of a single line of programming before executing any of the contents. The command message defines the final instrument state that is wanted without regard for the order of commands given. This eliminates the problem of programming an unallowed instrument state such as increasing FM deviation before increasing carrier frequency. However care must be taken that each individual message only defines one final instrument state and not several. With this HP-SL capability, the previous example can be changed to the following:

```
100  Output 719; “*RST”
200  Output 719; “Freq 500 MHz;Ampl:Lev 10; Stat on”
```

Since “*RST” defines a complete instrument state on its own, it cannot be combined with the other commands or it will be uncertain which state will result. This example also shows the use of the short form of commands as well as implied commands and implied units. The semicolon is used to separate commands in a single output, and the colon is used to separate words in a single command. The commands with asterisks are used with all IEEE 488.2 compatible instruments that can execute that function. In HP-SL commands, spaces should be between words and arguments but not before or after punctuation. Much more information on HP-SL programming with the 8645A is provided in the *HP-SL Programming Guide* (literature number 5951-6710).

Command sequence independence using HP-SL

A current problem with instrument programming is that each command that is received by an instrument is executed immediately. When the user is trying to set up a complete instrument state, the order in which the commands are sent must be correct so that each intermediate state is valid. Implementing HP-SL on the 8645A has eliminated this command order dependence through the creation of command "messages". A message contains all of the instrument commands that will result in the desired instrument state. None of the commands are implemented by the instrument until the complete message is received. In this structure, the order of the commands in the message is irrelevant. The programmer constructs messages to describe the final instrument state that is needed without worrying about the way the instrument gets to that state.

For example, suppose a signal generator had the following capability dependencies between carrier and FM deviation range:

Carrier range	FM deviation range
100 MHz to 1 GHz	1 MHz to 10 MHz
10 MHz to 100 MHz	100 Hz to 1 MHz

With the previous control structure, it is impossible to serially change the frequency and FM deviation because either command to go to another range will cause an error as the other parameter is out of range. The programmer would have to create an intermediate state such as turn FM off before changing the frequency so that all intermediate states were valid. The Performance Signal Generator (PSG) implementation of the IEEE 488.2 standard eliminates this problem because only the final state need be valid. The message of "Freq 200 MHz; FM 8 MHz" would put the instrument right to the new state that is wanted.

It is important that the user does not define an ambiguous state within a message by modifying the same function more than once in a single message. It is uncertain (and undefined) what the final instrument state would be if the 8645A received the following messages:

```
Freq:step 10 HZ;:Freq up;:Freq:step 100
HZ;:Freq down
```

As the frequency is repetitively changed in a single message the final frequency of the instrument will depend on the execution order of the commands, which is not defined.

```
*RST;Freq 123 MHz;FM:State on
```

In this case the *RST command could be executed after the other commands, canceling their effects. The command *RST defines a complete instrument state by itself and so should be sent alone.

```
FM:State on;:AM:State on;:Mod:State
off;:Freq 100 MHz;:Mod:State on
```

In this case the user has specified conflicting states for the mod:state command.

If the execution order of a group of commands is important, the user must send a separate message for each command.

Performance related topics

Phase noise performance

The 8645A agile signal generator was designed to minimize the phase noise of its signal at offsets corresponding to typical channel spacings of communication systems. These offsets of interest are generally greater than 10 kHz from the carrier. Simultaneously, the close-in noise was reduced to assure low residual FM for receiver testing. The following summarizes the phase noise performance of the 8645A.

For offsets less than 100 Hz, the primary contributor of phase noise is the fractional N synthesis circuitry in a single phase lock loop if FM is not active. A typical level is –80 dBc (in a 1 Hz noise bandwidth) at 100 Hz offset for carriers in the main band of 515 to 1030 MHz. The phase noise at offsets between 100 Hz and 10 MHz is determined primarily by a frequency discriminator inside a frequency locked loop. The typical phase noise level at a 20 kHz offset is –133 dBc in the main band. Beyond 10 MHz the phase noise is that of the VCO or output section divider noise floor at approximately –150 dBc. These phase noise levels at offsets less than 10 MHz will decrease by approximately 6 dB each time the carrier frequency is reduced by half due to the dividers in the block diagram. This phase noise reduction continues until the dividers' noise floor of approximately –150 dBc/Hz is reached.

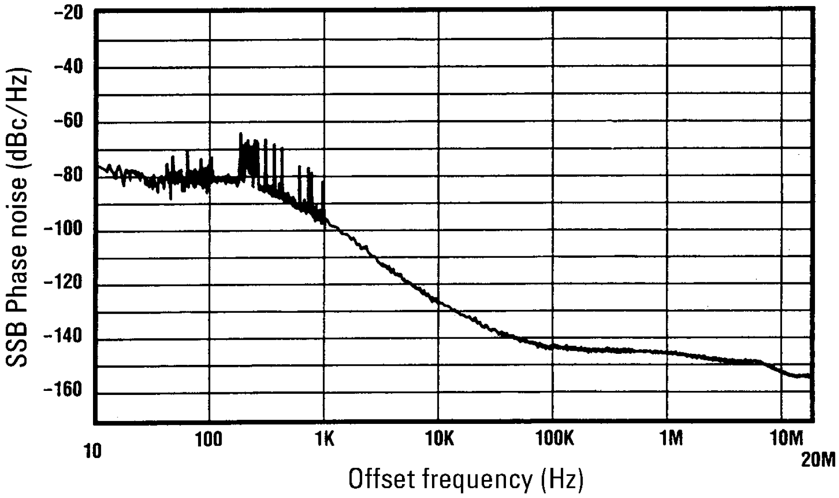
At offset frequencies of 20 kHz or greater phase noise does not increase when FM is active as long as the deviation used is less than approximately 5% of the maximum FM deviation allowed at that carrier frequency. For example, in the main band of 515 to 1030 MHz the maximum available deviation is 10 MHz, but the phase noise performance at a 20 kHz offset remains the same as in CW operation if 500 kHz or less of FM deviation is set by the user. If the full 10 MHz deviation is used, the phase noise at this 20 kHz offset typically increases by 17 dB to –116 dBc.

As with any signal generator, close-in phase noise of the 8645A goes up as the FM deviation increases. This is because the internal FM circuits contribute more noise as the deviation (gain) increases. For example, the phase noise level is approximately –80 dBc at a 10 Hz offset for a main band output from 515 to 1030 MHz with FM deviation set to 100 Hz. If FM deviation is set to 100 kHz the phase noise at this offset increases by 35 dB to typically –45 dBc. Using the full 10 MHz deviation, the maximum available in this main band, phase noise will go up another 40 dB to approximately –5 dBc at a 10 Hz offset.

There is no degradation of phase noise at offsets greater than 10 kHz if special function 120 "Linear DCFM" is activated. At smaller offsets however ,linear FM operation will result in up to 35 dB less noise for operation using high FM deviations. For example, at a 10 Hz offset and with 10 MHz FM deviation set, the phase noise level in the default FM mode is typically –5 dBc while the linear FM level will be at –35 dBc. Similarly for a 1 kHz offset the levels are typically –51 dBc and –77 dBc. At a FM deviation of approximately 20 kHz the level of phase noise is about equal for the two FM modes while at smaller deviations the default digitized FM actually exhibits lower phase noise. In general, the linear FM special function may improve phase noise performance at offsets less than 10 kHz when FM deviations greater than 20 kHz are in use.

In summary, the 8645A will add the least amount of phase noise to the carrier if the lowest FM deviation necessary for the application is used.

Phase noise levels in fast hop operation are degraded approximately 3 dB from non-agile levels due to a reduction of filtering on the VCO pre-tune lines. Less filtering is necessary, as the signals on these lines require a higher bandwidth during fast hop operation. The typical level of phase noise for frequency agile signals between 515 and 1030 MHz is –130 dBc at a 20 kHz offset.



8645A signal generator typical phase noise and spurs at 1 GHz

Spurious performance

The spurious performance of the 8645A is quite good, but there are still spurs to be found. This product note describes the sources of potential spurs and where in the spectrum they can be found.

The harmonically related spurs are caused by nonlinear operation of amplifiers in the RF path. The specification for harmonics of the carrier for carrier frequencies below 1030 MHz is –30 dBc. Typically, they are better than –35 dBc. Subharmonics typically are caused by a divider in the Phase Lock Loop (PLL) signal path that affects the main VCO output and amplification in the output section. The dominant subharmonic is at 0.5 * the VCO frequency. This spur in the main band (515 to 1030 MHz) is less than –70 dBc, in the doubled band (1030 to 2060 MHz) it is less than –45 dBc, and below 515 MHz it is practically non existent.

Nonharmonically related spurs are caused by a number of things. These include the power supply, microphonics, and digital circuits. The power supply spurs are all input line frequency related and are typically less than –60 dBc in the main band. A careful design of the regulators and power distribution circuits keeps the power supply ripple in the instrument very low. The front panel display circuitry can produce a spur at an offset of approximately 1.5 kHz. Its level is less than 20 dB above the signal generator's phase noise measured in a 1 Hz noise bandwidth. Microphonics is another source of spurs that depends on how severe the signal generator is being vibrated. One inherent source is the fan, with the location of the spur dependent on fan speed which in turn is a function of the instrument's temperature. The fan spur is usually less than 20 dB above the noise.

A spur can be produced in the output when external modulation (i.e., FM) is enabled and the internal audio source is active. Its location will be at the audio source frequency. The level will depend on the amount of FM deviation programmed. For example, if 1 MHz deviation using an external FM source is set and the internal audio oscillator is at 100 kHz, it will cause a spur at approximately –80 dBc. It is recommended that the audio oscillator be turned off when not in use.

One final type of spur to be mentioned is due to the fractional-N circuitry in the PLL. When the output frequency in the main band is not an integer multiple of 400 kHz, a spur will be produced. This spur is caused by the PLL divider alternating between two divider numbers (integers) such that the average frequency is the desired frequency. Compensation in the PLL circuitry keeps these spurs to less than 25 dB above the phase noise of the output signal (in a 1 Hz noise bandwidth). The fractional-N spur frequency in the main band will be at half the difference between the closest integer multiple of 400 kHz and the instrument's output frequency.

Third order intermodulation

Third Order Intermodulation (TOI) products result when the outputs of two signal generators are summed together in a combining network. These spurious signals occur at frequencies 2*F1-F2 and 2*F2-F1, where F1 and F2 are the output frequencies of signal generators 1 and 2 respectively. The unwanted intermodulation signals are the result of the Automatic Level Control (ALC) loops in the output sections of each generator “seeing” the other generator’s signal and responding to it as if it were unwanted modulation on the desired output signal. If the frequency difference between the desired output signal and the other generator’s signal is less than the bandwidth of the ALC loop, the loop can respond to the signal’s presence. In trying to remove this single sided “modulation”, the loop inadvertently produces modulation sidebands of its own. This unfortunate process is also occurring in the other generator’s ALC loop at the same time. The overall result is third order intermodulation products accompanying the two test signals at the output of the combiner.

Since signal generator outputs are usually combined to provide a stimulus to test the TOI performance of receiver front ends, it is important that the TOI products caused by the signal generators be well below those expected from the device under test. One way to reduce the TOI products from the signal generators is to use a directional coupler rather than a resistive summer to combine the two signal generator outputs. Another way to decrease TOI products is to reduce the bandwidths of the signal generator ALC loops well below the frequency spacing used. This approach can be taken to the extreme of entirely opening (or disabling) the ALC loops, since an open loop can be thought of as an infinitely narrow (0 Hz) bandwidth because the ALC will not respond to a signal at any frequency.

The 8645A has five different ALC loop bandwidths: 200 kHz, 50 kHz, 5 kHz, 60 Hz, and 0 Hz. The instrument automatically selects the optimum bandwidth for lowest AM distortion, fastest amplitude switching speed, and lowest TOI. The three widest bandwidths are used only when AM is enabled. In that case, the bandwidth selected is a function of carrier frequency. The 60 Hz bandwidth is used whenever AM is turned off. At this bandwidth, the TOI level produced by two signal generators with a frequency difference of 25 kHz and with output levels of +8 dBm is typically less than –55 dB. For better performance with smaller frequency differences, the 0 Hz bandwidth can be selected using special function 104.

Divided outputs below 515 MHz

To create signals below the main VCO frequency range of 515 to 1030 MHz, the 8645A divides the VCO into lower frequency octaves using digital dividers switched into the signal path. A total of 11 divide bands extend the frequency coverage down to 252 kHz. This technique is very good for spectral purity as with each division of the signal the phase noise and spurs are decreased approximately 6 dB. This reduction in phase noise continues until the noise floor of the dividers is reached which is typically approximately –150 dBc. Residual FM is also reduced as the carrier frequency is divided down. However, there are other consequences that must be dealt with as the following describes.

When FM is applied to the VCO the amount of deviation that is present in a divided output is divided by the same number as the carrier. For the lowest or 11th divider band this division equals 211 or a divisor of 2048. This large divisor is one of the reasons the 8645A has a maximum of 10 MHz of FM deviation in the main band. With this large deviation available in main band there is still 10 MHz / 2048 or 4.8 kHz of deviation available in the 252 to 503 kHz band. FM rate also decreases with each successive divide band because each band has 2 half-octave low pass filters present to reduce the level of harmonics at the output.

Phase continuous frequency sweep is also reduced by the action of the divider circuits. The actual frequency change in this function is an FM operation using the full FM deviation available in the main band to get a 20 MHz span (±10 MHz). The available span width is reduced by half with each successive divide in the same way FM deviation is.

The AM bandwidth is always limited to something much less than the carrier frequency because the level detector (which is designed to follow the AM envelope or any level variation and not the RF) would start detecting the RF waveform if the bandwidth were too wide. In a divided output, the AM is applied to the divided RF output (not the main VCO signal) and therefore the AM bandwidth must be less than the band's lowest RF signal so as not to react to the carrier. But as AM bandwidth is reduced, amplitude switching time gets longer and AM distortion is worse. In the 8645A three AM bandwidths are used to optimize the AM performance and still allow fast amplitude transitions as is necessary for fast hop operation. Over the frequency range of 128 to 2060 MHz a 100 kHz bandwidth is used, a 50 kHz bandwidth is active for signals down to 8 MHz and a 5 kHz bandwidth limits signals for outputs to 252 kHz. In fast hop operation, the amplitude is decreased by approximately 30 dB by the AM circuitry during each frequency change of the main VCO. The reduction of AM bandwidth for the lower divide bands which causes slower amplitude switching time is the only reason the fast hop switching time is longer for low carrier frequencies.

Stereo separation quality

Stereo separation is a measure of a receiver's ability to separate the left and right channel of a stereo signal. To a listener, this is a measure of the receiver's ability to recreate the spatial impression of a stereo signal. In an FM system the audio information is received as a left + right signal and a left-right signal. The receiver decodes the left channel by adding the two signals and decodes the right channel by subtracting the two signals. The separation of the channels depends on the cancellation of the right channel during the addition and cancellation of the left channel during subtraction. For this to happen properly, the relative phase and amplitude of the two original signals must be kept equal.

In a signal generator the FM linearity and group delay flatness determines whether the relative phase and amplitude of the stereo signal is preserved. Typically, test signals near 1 kHz and 38 kHz are used to modulate the signal generator to test stereo separation in a receiver. The quality of the test signal, and therefore the measurement, will depend on the FM linearity and group delay at these frequencies.

Radio manufacturers specify stereo separation in dB as the amplitude difference between a desired signal in one channel and an undesired signal in the other channel. The desired signal is a known test signal used to stimulate one channel. The undesired signal is the unwanted "leakage" or coupling of the test signal into the other channel. Radio manufacturers typically specify 40 dB separation which is beyond most listener's ability to detect distortion or "crosstalk" between the channels.

The 8645A in the fast hop operation uses linear FM and has low group delay. Typical stereo separation is greater than 55 dB in this mode and is sufficient to test most consumer radio equipment. Using digitized FM in standard operation of the 8645A will result in poor stereo separation due to variations in the group delay of the FM signal path. Activating special function 120 linear FM with AC coupling set provides separation similar to the fast hop mode but has the disadvantage that signals below 20 Hz cannot be used. Linear FM with DC coupling also has good stereo separation but poor center frequency resolution. Therefore, for the best stereo separation with the 8645A the user should activate the fast hop mode with DC coupling.

Minimizing fan noise

Increasing concern over the level of audio noise coming from test instruments has resulted in several design features to minimize noise from the Performance Signal Generator (PSG). The objectionable noise from test instruments comes from the fans used to create the internal airflow to cool the electronics and prevent heat related failures. These modifications from what was done in the past are related to careful fan selection, fan speed and rear panel fan cover. An overriding consideration was to maintain the high reliability design goal for the PSG by ensuring sufficient airflow for cooling components.

A number of fans were evaluated for use in PSG. Along with being of the right physical size and pushing enough air, the noise level when running was considered. Of the fans that would meet the cooling requirements, the one with lowest noise level was chosen. The next step was to evaluate the noise contribution the fan cover was responsible for. The shape of the grill work of the cover changes the noise level due to the fan blades passing close to it in their rotation. An analysis of noise sources of various grill shapes with the blade shape of the low noise fan led to making several grills to try out. The combination of the grill and low noise fan that produced the lowest noise was chosen for implementation in PSG.

The final step taken to reduce the noise of the PSG produced the biggest benefit for the average user. Minimum airflow required for high reliability operation is calculated assuming the ambient temperature at the maximum operating temperature specified. For PSG, this temperature is 55 degrees centigrade (131 degrees fahrenheit). Fan rotation speed is set to provide enough airflow at this high environmental temperature. At lower temperatures, less airflow is needed to keep internal components at their specified operating temperature so the fan speed could be reduced. In most previous instruments the fan speed is held constant at the highest airflow needed for high ambient temperatures. In PSG instruments, the fan speed is controlled by a temperature sensor to vary airflow as needed to maintain as much as possible constant internal temperature over the full environmental range of 0 to 55 degrees centigrade. Since the average user has the instrument in environments much less than 55 degrees centigrade, the fan speed is much slower than the maximum it could do. As fan noise is directly related to the fan speed, in typical use the PSG instruments are much quieter than previous signal generators. This provides a much more pleasant environment for the operator of a performance signal generator.

Frequency agility

Functional description of frequency agile operation

The frequency agile operation of the 8645A is unique in both its capabilities and its operation. The following describes what the instrument is actually doing while in fast hop operation.

Entering the fast hop mode

Either pressing the fast hop mode select key or sending the counterpart HP-SL command will put the instrument in the fast hop synthesis mode. The instrument's output frequency is no longer phase locked. Instead the frequency accuracy depends on an extremely stable VCO and a frequency locked loop. At this point the fast hop subsystem is set to idle allowing parameters such as output level and FM deviation to be programmed the same as in non-agile operation.

Entering channel information, hop rate, and dwell time

As the user enters each frequency and amplitude into a channel location, the information is put into non-volatile memory for use during the learn operation that precedes frequency hopping. If a channel sequence is entered for the channel numbers, this information is also put in this memory. A hop rate and dwell time are always in memory and are modified according to any new values entered. Any conflict between the hop rate and dwell time is not checked until the frequency learn operation is initiated.

Initiating the learn operation

The learn operation recalls each frequency and amplitude stored in each channel location and sets the phase locked synthesizer and the ALC of the output to each value. At each setting the instrument records the VCO tuning voltage and the ALC amplifier gain. The output is turned off while this process is underway. The hop rate and dwell are also verified that they will not conflict for the frequencies (and associated switching time) in the channel table. The only channels that are part of these operations are those in the current sequence table. If the user did not specify a sequence table, the 8645A creates one that reflects the number and order of the entries in the channel table. The instrument does not program frequencies and amplitudes of any channels that are repeated in the sequence table, rather the VCO and ALC settings already learned are copied into memory. The learn operation always lasts a minimum of 10 seconds to ensure that the hopping circuits are exercised sufficiently to stabilize any thermal changes in the transition from the idle state. As more unique frequencies are included in the channel table it takes longer to set up each state to record the settings and so the learn time required increases. For 2400 channels, learn time is approximately 1 minute. This time doubles to 2 minutes if FM is active.

Initiating hop operation

When the 8645A begins frequency hopping a unique "fast controller" takes control of the VCO and ALC. The data contained in the fast hop memory is presented to the hardware to duplicate each channel in the order it appears in the sequence table. Depending on which fast hop mode is active, the fast controller may cycle through the sequence table at a programmed rate or enable external inputs to trigger a hop to the next channel or to select which sequence location to output based on the input at the fast hop bus. The instrument will remain in the hop state until the idle or learn operation is selected or a function is changed that would invalidate the data in the fast hop memory (such as changing the FM deviation). Rate and dwell can be changed without having to learn again.

Faster frequency switching using multiple agile generators

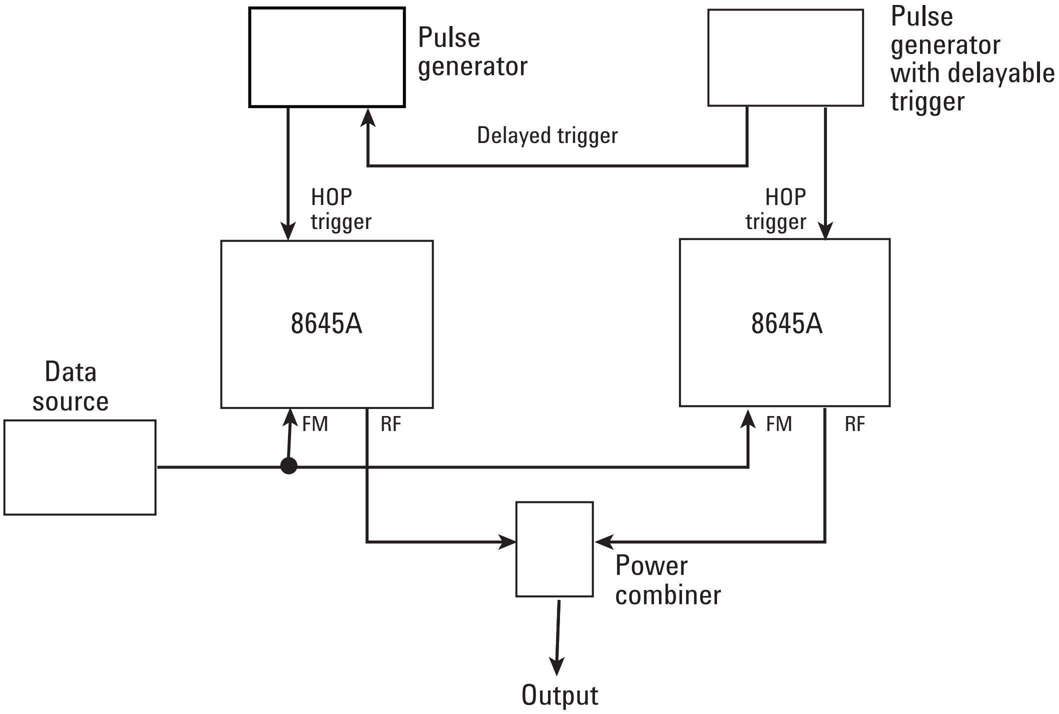
The 8645A can provide frequency agile outputs with hop rates of up to 50,000 hops/second depending on the carrier frequencies above 128 MHz, 11,000 hops/second above 8 MHz, and 2,000 hops/second above 252 kHz. While these hop rates are fast enough for the majority of agile applications, sometimes higher hop rates may be needed. The 8645A has been designed to make it easy to synchronize and combine the outputs of multiple units in order to create agile signals at higher hop rates. This product note explains how to configure multiple units to work together.

Frequency agile operations that include interfacing with a radio usually involve control of the following parameters: frequency selection, data valid, hop triggering, dwell time, modulation and amplitude. Of these parameters only data valid and hop triggering require extra attention when synchronizing the outputs of two or more 8645A's. In a typical instrument set-up, each 8645A will have loaded into memory identical channel and sequence tables of all the frequencies and amplitudes to be output. Dwell time for each hop frequency will be constant and controlled by the instrument's internal timers. The modulation waveform to be placed on the carrier would be input to both external FM inputs with the same FM deviation set on each generator. The frequency control word to select each channel to be output according to its location in the sequence table would also be input to the fast hop bus of both instruments simultaneously. The RF output of each generator would be brought together with a combiner for input to the device under test. All of these control inputs and instrument settings are identical to that required for operating a single 8645A.

By alternating which signal generator receives the data valid and hop trigger signals it is possible to give one 8645A time to switch frequencies while a second unit is producing the needed output. Then while the second unit is changing frequencies the first can provide the next output. In this way the combined agile output can be switched at much higher rates than are possible with a single 8645A. Each unit gets a trigger signal at half the hop rate of the combined output will be. The data valid input to clock in each frequency word occurs at the same time as the hop trigger but is input to the opposite instrument. Consequently the same trigger signal (approximately +5 volts for 1 usec) can be used for both the hop trigger of one unit and the data valid input of the other unit since the two signals occur simultaneously but are just routed to two different inputs.

Although both generators get the modulating signal, only the generator that is presently outputting a signal will carry the modulation since the output of the other generator is decreased by over 60 dB while it is changing frequencies. Also the frequency word that goes to both fast hop bus inputs is ignored by the generator that does not also get a hop trigger to implement the word.

The diagram that follows illustrates the connections that will alternate outputs from two agile signal generators to produce a hopped signal at rates above 50,000 hops/second for carrier frequencies above 128 MHz. Note that two pulse generators (such as an 8116A), one with a delayable trigger (such as an 8013B), are used to provide a hop trigger alternately to each generator. Frequency selection is controlled by the internal sequence table of each generator so the frequency control word and data valid inputs are not needed. The two outputs are combined using a power splitter such as the 11667A. With this configuration a maximum hop rate of 93 kHz can be produced with a switching time of 4.3 microseconds between channels and a dwell time of 6.4 microseconds per frequency. By increasing the dwell time of each agile output the switching time can be reduced. To calculate the combined output switching time, it is only necessary to subtract the dwell time from the 8645A's specified switching time for the carrier frequency range in use and divide by two. For example, if the signals were at carrier frequencies below 8 MHz with a specified switching time of 500 usec and the desired dwell time was 300 usec, the switching time of the combined output would be (500 usec minus 300 usec)/2 or 100 usec. These signals would have the same specifications of ±2 ppm frequency accuracy and ±1 dB amplitude accuracy as an 8645A operating by itself would have.



Multiple signal generators provide faster frequency switching

Frequency accuracy of agile outputs

The frequency accuracy and stability of the 8645A is directly related to the 10 MHz timebase used as a reference for non-agile operation. The output accuracy is a direct multiple of the timebase error. For the high stability timebase specified at 0.0005 parts per million (ppm) aging rate per day, the worst case error of a 1 GHz output after 10 days would be 5 Hz assuming no initial inaccuracy.

For frequency agile outputs, the 8645A specifies a maximum error of ±2 ppm. There are two contributors to the frequency error: timebase error and temperature related drift. Timebase error is a factor because during the “learn” operation the 8645A briefly synthesizes each output frequency using the phase lock loop circuits and reads voltage levels of the VCO tuning line. While hopping this tuning voltage is sent back to the VCO to create the output signal very rapidly. Any error of the timebase will be reflected in the tune voltage sent to the VCO used for fast hop signals.

Temperature related frequency errors result from a change in the operating temperature of the components in the agile signal path. Several steps have been taken to reduce the temperature variations within the instrument such as providing constant-temperature heating of the delay line and temperature regulating the fan speed that provides cooling. These design features and the large thermal mass of the instrument greatly reduce the sensitivity of the 8645A’s agile frequency accuracy to ambient temperature changes. In any case, it is recommended that the user re-learn the hop frequencies before beginning a frequency agile test. Each learn operation will remove any temperature related offset between the fully synthesized calibrating signal and the agile output. Also, as noted in the specifications table, having the unit plugged-in for 24 hours and operating for a minimum of 2 hours before the learn operation and frequency hopping begin, will ensure the heating elements and the thermal mass of the instrument are at a stable operating temperature.

The typical worst case frequency error of ±1 ppm for agile frequency outputs can be significantly improved if the test parameters for the application are within a certain criteria that minimizes the minute thermal variation of the agile components themselves. For example, tests conducted during the 8645A’s design show that the frequency error is reduced for agile test sequences of less than approximately 60 unique frequencies with hop rates of greater than 10 hops/second. The same improvement occurs for internally controlled sequences having up to the maximum number of 2400 unique frequencies as long as the distribution of how often each frequency is output is pseudorandom. The average frequency error measured under these conditions was less than ±0.3 ppm.

Relating phase error and frequency accuracy

The quality of a signal can be specified in many ways including amplitude accuracy, spectral purity, output level, modulation distortion, etc. A common specification of many sources is frequency accuracy or phase error. While many signal generators are specified in terms of frequency accuracy, other types of sources are just as commonly described with a phase error. Since the signal generator is often used to simulate or substitute for a source specified in terms of phase error, it becomes necessary to convert between frequency accuracy and phase error to determine if performance is sufficient. This calculation is of critical importance for frequency agile sources that are specified to be within a stated frequency accuracy or phase error in a certain amount of time after a frequency change is triggered. This product note discusses the conversion between phase error and frequency accuracy.

Converting a phase error specification to a frequency accuracy number is based on a key assumption: that the phase settling characteristics are approximately linear. Since the rate of phase change of a signal is related to its frequency, knowing that a source's output is uniformly approaching the desired final phase state allows a calculation of the corresponding frequency change. If the phase settling departs significantly from linear, the calculated frequency error will be too low for faster phase settling and too high for slower settling signals. The following examples use typical characteristics for a frequency agile local oscillator to illustrate the phase error to frequency accuracy conversion process.

Example 1: Converting phase error to frequency accuracy

A local oscillator switching in the range of 800 to 1000 MHz is specified to be within 0.1 radian of final phase 20 usec after the frequency change trigger is received. The signal settles to the final phase during the 5 usec duration of the output. Converting the accumulated phase error over the 5 usec duration results in a calculation of (0.1 radians)/(5 usec) equaling 20,000 radians/second that the signal is changing. This equals a frequency error of (20,000 rad/sec)/(2*pi rad/sec) or 3183 Hz. The frequency accuracy of the 8645A is specified at ±2 ppm of the carrier which translates to a maximum of 2 kHz frequency error for the 800 to 1000 MHz frequency range. In this application the 8645A can substitute for the local oscillator as far as the frequency accuracy requirement is concerned.

If in the previous example the signal settled to its final phase faster than 5 usec, the calculated frequency error would be correspondingly higher. Another example follows which converts the frequency accuracy of the 8645A to its corresponding phase error for the previous example.

Example 2: Converting frequency accuracy to phase error

The frequency accuracy of the 8645A is specified at +2 ppm of the carrier frequency. For a 1 GHz output this equals a maximum error of 2 kHz. Converting 2 kHz to a phase error equals (2000 Hz)*(2*pi rad/sec) or 12,566 radians/sec. In the 5 usec duration of the signal described in example 1, the maximum accumulated phase error is (12566 rad/sec)*(5 usec) or 0.0628 radians.

If the phase error is specified in terms of degrees the values given in radians in the above examples should be multiplied by (2*pi). In example 2 the 8645A's phase error of 0.0628 radians translates to 0.3946 degrees.

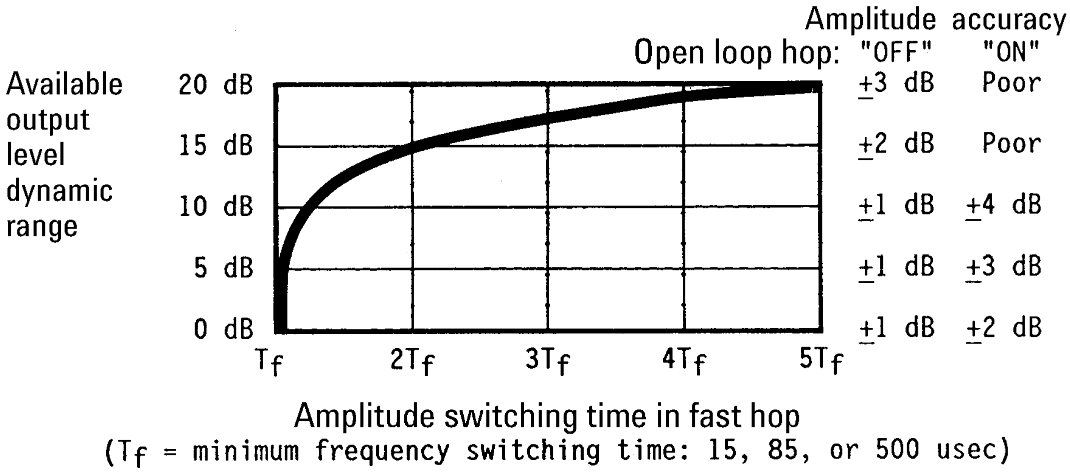
Amplitude dynamic range while frequency hopping

The available output level dynamic range in fast hop mode is a function of the amplitude switching time required. The frequency switching time of the 8645A is not controllable by the user and is always typically 9 microseconds, the speed of the fundamental VCO. The specified switching times in the data sheet are actually amplitude switching times, that is the time it takes for the power to rise to 90% of its final value at the new frequency. This “power rise time” is also not directly controllable by the operator, but he can effect it by utilizing the amplitude hopping capability of the 8645A.

The 8645A hops with the ALC loop closed unless the operator selects [open loop hop “on”], special 202. For [open loop hop “on”], amplitude switching time does not degrade as a function of amplitude range utilized, but level accuracy does degrade. For [open loop hop “off”], special 202, the default mode, the available amplitude range is a function of the amplitude switching time required. This range can be used for either programming different levels or for shaping the power envelope (using the AM port) while hopping. Both capabilities can be used simultaneously as long as the total range is within the limit described in the graph below. Note that the amplitude accuracy is also a function of the range utilization and ALC special selected. The level accuracy degradation will occur at the lower amplitude output.

The typical, quantifiable, degradation in amplitude switching time and level accuracy is described in the graph below. Amplitude variations greater than 20 dB may be programmed, but amplitude inaccuracy could become much greater than 5 dB in some cases.

The reason for these interrelationships is, the same ALC loop is used simultaneously for DC coupled AM and level setting. To provide specified 90% AM with adequate design margin, 30 dB of ALC range is required at the worst case frequencies. The instrument was designed to give the user the option of using this “excess” range to control level while fast hopping. At the lower portions of this “excess” ALC range, the ALC loop bandwidth will decrease, increasing the amplitude settling time.



(Tf = minimum frequency switching time: 15, 85, or 500 usec)

Amplitude shaping of agile outputs

As part of their frequency switching algorithms, many frequency agile radios reduce the RF carrier power when switching between frequencies. Since controlling the characteristics of the amplitude transitions while switching is critical to proper hopped operation, the 8645A was designed to allow the user to shape the amplitude transitions of the RF carrier while in fast hop operation.

If the amplitude transitions are very sharp in nature, a frequency agile carrier (when viewed at one specific frequency) will have the same sin (X/X) spectral signature as a pulsed RF carrier. As with a pulsed RF carrier, the energy of the carrier will be distributed throughout the lobes of the sin (X/X) envelope. This energy distribution is typically of no concern in pulsed applications but in frequency agile applications the distributed energy can fall into adjacent communication channels, causing disruption of communications in those channels. To avoid this problem, frequency agile radios that reduce the RF carrier power when switching also shape the RF power transitions to minimize the spectral splatter associated with sharp (pulse like) amplitude transitions.

When in fast hop operation, the 8645A automatically ‘softens’ the amplitude transitions to decrease the spectral splatter. As power is being shut off at a specific hop frequency, timers built into the instrument send a negative step to the ALC loop so that the amplitude drops at a rate that is consistent with the ALC loop bandwidth. After several microseconds the ALC loop will have decreased the output amplitude by approximately 30 dB. At this point the pulse modulator is activated to get an additional 35 dB or more of amplitude decrease. This timing sequence is reversed when the power is being brought up at the new frequency, with the pulse modulator being turned off first and then the ALC loop being allowed to return to its pre-shutoff level. This sequence greatly reduces the spectral splatter from what it would be if only the pulse modulator were used. If the user activates special function 202 ALC off, to get slightly faster frequency switching speed, the ALC is not used to decrease the output power. Only the pulse modulator would be used so spectral splatter increases somewhat due to the more abrupt amplitude transition. Additionally the power is only decreased approximately 35 dB between frequency hops.

The operator that would like to use the 8645A to emulate a transmitter that uses a rigorous amplitude shaping technique, or who needs to decrease spectral splatter for other reasons, can use the external DC AM port to shape the amplitude transitions during fast hop operation. The shaping signal, such as a raised cosine wave, when input into the external DC AM port controls the ALC loop to implement the amplitude shaping. To shape the amplitude rise and fall characteristics of a hopped signal, the shaping signal must be synchronized to the hop trigger or dwell time control (available on the rear panel of the 8645A). It should be noted that external shaping, as well as the automatic shaping previously described, use some of the available ALC range. This means that the amount of amplitude variation available while hopping is decreased. Elsewhere in this product note the interaction between amplitude hopping range, frequency switching speed, and amplitude shaping is discussed as “Agile Amplitude Dynamic Range”.

Modulation

High rate, high deviation frequency modulation

The 8645A has overcome many of the previous barriers to provide FM with high deviation in an RF signal generator. By using digital techniques, deviations as high as 10 MHz are possible for carrier frequencies in the main carrier band of 515 to 1030 MHz. Accompanying this breakthrough in high deviation FM is a similar increase in the maximum rate of FM to 10 MHz. One reason for this extra FM performance is to ensure sufficient usable capability after the many divider stages that extend frequency coverage down to the minimum carrier output of 252 kHz.

In the 8645A, the amount of FM deviation selected determines the length of the delay line used in the delay line discriminator placed around the VCO to reduce phase noise. At higher selected FM deviations the delay line is shortened so that it does not reduce FM sensitivity in the deviation range that is set. With a shorter delay line the phase noise from the VCO increases, but generally this is acceptable for applications needing high FM deviations. The annunciator for the mode 1 key on the front panel lights up when the shorter delay line is in use. As FM deviation is reduced below approximately 17% (1.76 MHz in the main band) of the maximum allowed at each carrier band, the extra delay line is automatically placed in the VCO signal path unless the user has specifically locked the instrument into mode 1 using the mode select keys. Phase noise and spurs are reduced for operation using the smaller FM deviation and the mode 2 indicator is lit. In this way, the best spectral purity is provided for any FM deviation that is selected.

The 8645A has two different types of FM referred to as digitized FM and linear FM, both of which can be used with the internal modulation oscillator and/or an external source at the front panel. Digitized FM is the default type and utilizes an A/D converter to translate the modulating waveform into digital information that is used to modulate the fractional-N divider number. This provides FM at rates from DC up to the phase locked loop bandwidth along with the capability for high deviations. A wideband, high slew rate analog path sums the modulation signal onto the VCO tune line to allow FM at rates from the PLL bandwidth up to 3.75 MHz and typically to 10 MHz while retaining the high deviations.

Linear FM is activated using special function 120. In this FM operation the digital path is switched out leaving just the analog path for improved flatness and stereo separation. In mode 2 with linear FM, the PLL is not used and linear DCFM is available through the frequency locked loop. During calibration, offsets are nulled in this path to improve frequency accuracy in fast hop operation which always uses linear FM. Group delay is less than 1 usec in linear FM with a typical value of 0.1 usec.

The maximum deviation available is the divided result of the amount available in the main band of 515 to 1030 MHz. The maximum of 10 MHz deviation in this main band becomes 5 MHz in the first divide band of 207.5 to 515 MHz. The minimum deviation that can be set is 100 Hz in the main band and also gets halved by each divider band to a minimum of 1 Hz. The maximum available FM rate is also reduced by each divider section due to the half-octave filters present in each divider section to reduce the level of harmonics generated.

Simultaneous modulation

The 8645A has a wide range of combinations available for simultaneous modulation. Various combinations of amplitude, frequency, phase and pulse modulation are provided as follows:

With AM: FM, phase, pulse, FM and pulse, phase and pulse
With FM: AM, pulse, AM and pulse
With phase: AM, pulse, AM and pulse
With pulse: AM, FM, phase, AM and FM, AM and phase

In addition to these combinations, the modulating waveform can be provided from either the internal modulation source or from an external source via a front panel input The internal/external status of a given modulation type can be set independent from any other modulation type that may also be active. The following combinations of internal and external modulation waveform source are available for each modulation:

AM: Internal, external
FM: Internal, external, internal and external
Phase: Internal, external, internal and external
Pulse: External only

In simultaneous internal and external FM or phase modulation, an external signal of typically 30% or more of full scale input can be applied simultaneously with a full scale internal signal without any limiting occurring.

When using the internal modulation source, rates from .1 Hz to 400 kHz are available with a resolution of .1 Hz. Therefore the entire bandwidth of AM (100 kHz for carrier frequencies greater than 128 MHz) and phase modulation (150 Hz) as well as a major portion of the FM bandwidth can be covered with the internal modulation source. The level of the internal modulation signal can be adjusted with a resolution of .2% of full scale to provide improved resolution of level of various modulation types. The internal modulation source can also provide complex waveforms such as sawtooth and squarewave at rates up to 50 kHz and white Gaussian noise of constant amplitude from .1 Hz to 400 kHz.

The external modulation source input of all modulation types except pulse can be set to AC coupling as an alternative to DC coupling. In AC coupling all DC drifts and biases up to ±10 volts from external sources are blocked without degradation of performance. The lower 3 dB bandwidth in AC coupling for all modulation types is typically 20 Hz.

The input impedance of all the external modulation ports is 600 ohms, except the FM port. The external FM input impedance is 50 ohms to allow external modulation sources to provide signals up to 10 MHz with low loss. By activating special function 123 the user can route modulation signals from the phase modulation input to the FM circuitry. Since the phase modulation input impedance is 600 ohms, this capability provides higher input impedance for FM operation. The upper 3 dB FM bandwidth using this phase modulation input is approximately 2 MHz.

Digitized FM operation

Synthesized signal generators have traditionally generated FM with a phase lock loop dedicated for this purpose. For AC coupled FM, this loop remains locked while the frequency modulating signal is injected into the loop to FM the output. For DC coupled FM, the loop must be unlocked so that low modulating frequencies are not canceled by the loop feedback. However, unlocking the loop for DC FM allows the output frequency to drift, which can be a problem for some applications. The 8645A has this traditional implementation of FM operation as a special function (120). The standard FM implementation for the 8645A is one that removes the frequency drift problem of DC FM.

As standard operation, the 8645A uses a digital FM signal to modify the instantaneous synthesizer divide values in the fractional-N circuit. This method greatly reduces the frequency drift and offset that is usually associated with DC FM operation. The only remaining drift is related to the Analog to Digital Converter (ADC) which is typically much less than the drift of an open loop VCO. This modulation technique is also very accurate at low FM rates because the output of an ADC can be much more precise than the analog tuning curve of a VCO. A side benefit of major importance is that this technique does not introduce out-of-channel spurs. In a traditional signal generator block diagram, the FM loop needs to sum into the main loop with the unavoidable introduction of crossing spurs.

There are some disadvantages to this digitized FM technique. One is that the digitization and summation of the modulating signal takes time, resulting in approximately 30 usec of group delay of the modulating signal at rates inside the PLL bandwidth. The non-flat group delay may cause distortion of the modulating signal, and in some instances may actually cause the PLL to unlock. Another implication of this modulation scheme is that when digital FM is being used in a feedback loop, the quantization steps of the ADC may cause phase discontinuities. For these reasons some applications may require use of the traditional FM implementation available as special function 120.

The following describes the performance that results from activating each type of FM in the 8645A.

Center frequency accuracy and temperature stability:

For the digitized FM mode, the initial center frequency accuracy is typically 0.1% of the FM deviation set (typically 1% if in fast hop mode). Non-digitized or linear FM (special 120) has an offset of typically 1 kHz for any deviation in the 515 to 1030 MHz carrier band (offset divides for lower carrier bands.) The carrier frequency temperature drift with digitized FM active is typically less than 0.1% of the set deviation over the full operating range of 0 to 55 °C. The center frequency accuracy in linear FM will vary approximately 1 kHz/°C in the 515 to 1030 MHz carrier range.

Phase noise variations at low offsets:

For deviations less than 5% of the maximum deviation available at any carrier frequency, digitized FM operation negligibly affects the phase noise performance of the output. The noise increases with higher FM deviations. For linear FM, the phase noise at low offsets goes up by 20 dB when activated but does not increase as much for higher deviations as it does in digitized FM. In general, special 120 linear FM may improve phase noise performance over the digitized FM at offsets less than 10 kHz when deviations greater than 20 kHz are in use. The topic “Phase Noise Performance” in this product note has more information on this subject.

FM deviation accuracy:

For modulation rates <1 kHz, deviation accuracy for the digitized FM is a function of the ADC, typically <1% of the set deviation. For linear FM it is approximately 5%. At higher rates, the deviation accuracy is dependent on analog factors which makes it the same for either FM technique.

Square wave or digital modulation waveforms:

For linear FM the group delay is very flat and typical of other signal generators. The group delay of digitized DC FM is a function of the modulating rate. For single-tone modulation signals or if the spectral energy is primarily below 10 kHz, group delay in digitized FM operation is constant and will not affect the output signal. For high rate or digital modulating signals, the variable group delay of digitized FM could cause serious distortion so linear DC FM should be selected.

AC coupled FM

This product note builds on the information given in the digitized FM operation product note to explain the operation and resulting performance of AC Coupled FM (ACFM).

The 8645A has digitized and linear ACFM capabilities. Digitized ACFM is simply AC coupling of the digitized DCFM described in the “Digitized FM Operation” product note. The default digitized DC Coupled FM (DCFM) utilizes an Analog-to-Digital Converter (ADC) to digitize the incoming modulating signal as it occurs and uses the digitized information to modify the synthesis dividers. Low frequency 3 dB bandwidth of digitized ACFM is approximately 7 Hz. This function should satisfy most applications if the slight frequency inaccuracy of approximately .1% of the programmed deviation can be tolerated. Care must be exercised that the complexity of the modulating waveform does not cause unlocking or distortion problems as explained in the “Digitized or Linear FM” product note. Due to the very low drift of the digitized DCFM operation in the 8645A, there is less use for digitized ACFM. It should be noted that the 50 ohm input impedance to ground of the external FM input will be still there for ACFM signals.

The 8645A also offers special function 120 to get linear ACFM. This mode is more typical of the ACFM in other signal generators with the modulating signal input directly to the VCO except that the phase lock loop that is modulated has a much wider bandwidth than is typical. Because of this, the 3 dB low frequency corner is either 300 Hz or 3 kHz, depending on whether mode 2 or 1 respectively of the mode select keys is lit. If the user can tolerate this relatively high 3 dB frequency corner, the benefits this operation includes minimal group delay and precise center frequency. The applications where linear ACFM may be useful are when any frequency inaccuracy can’t be tolerated, or the group delay characteristics of the digitized FM can’t be tolerated, or unlocking occurs due to square waves at the FM port.

Special Capabilities

Tailored operation through special functions

In addition to the features directly available to a user through the front panel keys, the 8645A has a number of capabilities called “special functions”. These functions are accessed with the [Special] key in the utility field on the front panel and allow a user to customize operation of the instrument for a specific application.

Special functions or “specials” are functionally grouped by number as follows:

To find a particular special in the list, the user can scroll through the list by pressing [Special] and either turning the knob or pressing the up or down arrow keys. When the display shows the desired special, pressing [Enter] will access that special. A user may also press [Special] followed by the number of the special and [Enter] to access it. Pressing [Special] [Enter] will re-access the last special displayed. Once a special is accessed, it can be controlled with the same keys used for control of standard functions.

When displaying a special, the light above the special key will be lit if it is not at its default setting (the special is active). While scrolling through the specials as described above, the light will also come on when displaying the name of an active special. When no special is being displayed and standard functions are being used or displayed, this light will be lit if there are any specials active. Pressing the [Display] key followed by the [Special] key will show a list of all active specials.

100-109: Amplitude & ALC functions
110-119: Carrier control (phase, frequency multiplier, sweep mode)
120-129: FM functions
130-159: Audio source control
160-169: Frequency reference
170-189: Tests, calibration, security, volt/power meter functions.
190-199: Serial number, display control
200-210: Fast hop functions

Protecting classified instrument settings

The 8645A incorporates a number of functions to prevent the unauthorized exposure of classified instrument settings and readouts. They range from blanking the displayed readouts, to an automatic memory erasure if power to the instrument is interrupted.

The simplest function which has been present on many instruments for some time now is display blanking. With the 8645A, the entire display or specific functional readouts such as frequency or modulation can be blanked either from the front panel by activating special functions or using HP-SL commands via GPIB. This blanking includes all annunciator lights on the function specific keys as well as the alpha-numeric display. This will prevent the casual observer from seeing the instrument settings. To prevent an operator from unblanking the display by deactivating the special function another security-related capability, the local lockout can be initiated over GPIB. With local lockout active the instrument keyboard will not respond to the user until the controller removes the local lockout over the GPIB or until power is cycled. If power is cycled the machine returns to whatever state it was in before power was turned off, except that local lockout will be disabled.

A function called RAM wipe was created to allow the user to erase all user entered parameters and operation specific calibration data from the internal RAM. When this special function 172 is activated, a power-on reset is performed on the instrument. All RAM locations are cleared and tested with checkerboard patterns, and then cleared again. A side effect of this operation is that the instrument must spend a few minutes re-calibrating itself in order to restore the calibration coefficients in RAM. All storage registers are cleared, all fast hop sequence and channel data are also cleared. This feature satisfies the requirements set forth in Mil Std 380-380.

The three functions described so far, blanking, local lockout, and RAM wipe, can be used in combination with the security mode function for the highest level of security. Security mode special function 173, is like a one way operation in that no reduction of security is allowed, only increases. Activating security mode sets a flag in the instrument firmware such that all or part of the display can be blanked but not unblanked. If an instrument preset is performed, the instrument will remain in its current state of operation, with displays blanked and keyboard disabled if previously set, and the security mode still active. Security mode can be deactivated by turning special function 173 off or through an GPIB command. However, leaving security mode either way automatically and immediately initiates a RAM wipe operation. If power is cycled with security mode active a RAM wipe will be performed immediately when power is restored and the security mode will be deactivated. With security mode active the user can still gain control of the instrument, but not with any classified data parameters still present on the display or in memory.

Storage registers and sequential recall

Storage registers are used to store the current state of the machine for later recall. There are 50 storage registers provided in the 8645A. The storage registers use non-volatile memory so power interruptions won't affect the contents. Instrument preset has no effect on the storage registers, but activating the RAM wipe special function to remove all user-entered data from the instrument will erase them. Storage registers 0 through 9 store the entire machine state except for the fast hop channel data. (The fast hop channel information is held in non-volatile memory also, so power interrupts won't force a reload.) Registers 10 through 49 store only the current frequency and amplitude (frequency offsets/multipliers or amplitude offsets are not included). Any of the 50 storage registers can be recalled explicitly by specifying the register number.

Machine states are saved using the front panel keys by pressing [Save] <register number> (Enter]. To recall a register, press [Recall] <register number> [Enter]. All of the storage registers can be erased at once by pressing [Clear all] [Enter].

Registers can also be recalled in a user-defined sequence that has the instrument repetitively stepping from one register to another. Registers 0 through 9 can be included in the sequence list that can be up to 10 registers long including any repeated registers. A sequence is entered by pressing [Set seq] <first register number.> [Enter] <second register number> [Enter] ... continue to ... <last register number> [Enter]. There are several ways to recall registers from a sequence list. To repetitively recall the entire sequence, press [Auto seq]. Pressing [Off] stops this sequentially recall. To recall each sequence entry individually, either press [Seq] on the front panel or provide a +5 volt trigger signal to the Seq input on the rear panel. The entire sequence list in memory can be displayed by pressing [Display] [Seq].

Each of the functions described above has its counterpart HP-SL command for control over GPIB.

Offsets and multipliers of frequency and amplitude

The 8645A has several features which allow the user to streamline use of the instrument in applications where the frequency or amplitude of the instrument is scaled or offset by the user. This change of amplitude or frequency may be due to an amplifier, attenuator, cable, mixer, multiplier, divider, etc. For some applications, it may be more useful to control and display the frequency and amplitude in terms of a device's output rather than the RF output of the signal generator.

Amplitude offset allows the user to program into the 8645A the amount of loss or gain in the connecting device. For example, to control and display the amplitude at a device's input after a connecting cable loss of 1.2 dB, the user would press [Amptd ofs] <–1.2> [dB]. If the display previously read 0 dBm it will now read –1.2 dBm with an additional indicator "Offset" showing that an offset is in use. An offset to reflect the output of a 20 dB amplifier would be entered [Amptd ofs] <20> [dB]. The 0 dBm display would change to +20 dBm by these entries. All subsequent amplitude settings entered into the instrument will be displayed according to the new amplitude reference point. For example, entering an amplitude value of +5 dBm into the 8645A with a +20 dB offset active to reflect the output of an amplifier would actually produce –15 dBm at the RF output of the signal generator. In all cases, losses are entered as negative numbers and gains as positive entries. The maximum amplitude offset range is ±50 dB. Pressing [Amptd ofs] [Off] turns off an amplitude offset.

Frequency offset allows the user to enter a frequency shift between the RF output and the display of the 8645A to reflect the result of the signal passing through an external device. The operation of a frequency offset is similar to that of an amplitude offset. For example, if the user wants to produce an output that will be translated by a mixing process upward by 2 GHz and have the display reflect the result of the frequency translation, pressing [Freq ofs] <2> [GHz] will do it. All subsequent frequency entries will reflect the offset, ie. entering a 3 GHz frequency setting with the 2 GHz offset active will result in a 1 GHz signal coming from the RF output of the signal generator. A display that previously read 1 GHz will then read 3 GHz to reflect the output of the mixing process and the "Offset" indicator will be lit. Negative entries can be used to shift the RF output for a down-converting process. Frequency offsets are limited to ±50 GHz. To turn off a frequency offset, press [Freq ofs] [Off].

Frequency multiplier allows the user to enter a multiplier or divisor to modify the frequency output of the 8645A to reflect the action of a multiplier or divider connected to the signal generator. Frequency multipliers are entered using special function 111. For example, if an external device multiplies the signal by four, then pressing [Special] <111> [Enter] <4> [Enter] will produce an RF output that when multiplied by four will equal the entered frequency setting. The frequency display will show the frequency at the output of the multiplier. An "Offset" indicator is lit below the frequency readout. Any subsequent frequency entries will be in terms of the entered multiplier and not the actual output of the generator, ie. entering 1 GHz with a multiplier of 4 active will produce a 250 MHz signal at the RF output for multiplication to 1 GHz. Similarly, negative entries reflect a divider's action. A multiplier range of ±10 can be entered and only integer values are allowed. To disable the multiplier function, press [Special] <111> [Enter] <1> [Enter] which resets the frequency display for a multiple of 1.

When using a frequency multiplier, the FM deviation is scaled in the same way as the carrier frequency since an external multiplier or divider also multiplies or divides the amount of FM deviation. Therefore, if a multiplier of four was active in the 8645A, an entered FM deviation of 10 MHz would actually produce a 2.5 MHz deviation on the actual output of the signal generator and a displayed value of 10 MHz. Frequency offsets have no effect on FM.

Offsets and multipliers may be used simultaneously. When using both a frequency multiplier and a frequency offset, the displayed frequency equals (the output frequency) times (the multiplier) plus (the offset).

Built-in calibration functions

The 8645A was designed with no manual internal adjustments. All adjustments are under the control of the instrument firmware responding to a variety of sensors placed at strategic locations to monitor signal levels. This allows the instrument to adjust its signal parameters for an optimum output whenever the user wants. With this capability, the instrument can effectively calibrate itself by making adjustments to signal levels and recording the settings that result in the optimum and specified output signal. This calibration data is stored in battery back-up RAM so that the user will not have to repeat the calibration whenever the instrument is turned on. The self-calibration process typically takes approximately 2 minutes.

If the user suspects that the instrument is not performing correctly, a re-calibration of the instrument may be initiated by pressing [Special] <171> [Enter] [On] from the front panel or by sending the "*CAL?" HP-SL common query over GPIB. The instrument will display a result code of 0 if no errors occurred during the calibration operation.

The internal temperature is constantly monitored by the instrument to insure the optimum calibrated output. Since portions of the calibration data are temperature sensitive, the instrument will store the current temperature when calibrating along with the calibration data. If the temperature changes enough (approximately 10 degrees centigrade) to potentially invalidate the calibration data, a warning will be placed in the message queue to notify the user. If the user feels that the instrument performance is not satisfactory, the instrument may be re-calibrated at the new temperature using the special function.

Under certain conditions the calibration data may be lost or become corrupt, such as due to the following events:

1. Disabling the RAM using a switch on the Digital Control Unit (DCU).
2. Executing the RAM wipe special function.
3. Turning off the security function (which executes the RAM wipe function).
4. Failing a self-calibration or diagnostic test.
5. Removing the DCU from the motherboard.

If the instrument powers up without valid calibration data, it will automatically initiate a self-calibration. The exception to this is when the service mode switch on the DCU is enabled to prevent nuisance calibrations while working on an incomplete instrument.

Finding failures with internal diagnostics

The 8645A contains diagnostic routines in the instrument firmware which test the instrument hardware and will report over 90% of all instrument failures that could occur. These diagnostic routines will also isolate the cause of the failure to a replaceable hardware module or a cable. The diagnostic routines are activated from the front panel using an instrument special function or via GPIB commands and only run when initiated by the user.

There is separate circuitry built into the instrument that continually monitors high-level functionality (such as the phase lock loop being locked) and will put a message in the instrument message buffer should a problem be detected. However, this message is not specific enough to determine which module is the cause of the problem. When the user reads the message, the diagnostic routines can be activated to determine which hardware module is at fault.

There is special hardware in the instrument that makes these diagnostics possible. The digital controller contains a voltmeter with AC and DC measurement capability and each of the hardware modules contains at least one 8 channel multiplexer through which critical points on the modules can be measured by the voltmeter. A typical diagnostic routine would set a module to a specific operating mode and then set the multiplexer on that module so a critical point on the module can be measured. The routine would compare the voltmeter reading with the normal value. If the reading is not within preset limits, the routine will terminate testing and a result code is displayed on the front panel of the instrument indicating where in the test sequence the failure occurred. If the reading is normal, the routine continues to set the module to all its operating conditions and measures critical circuit points for each set of conditions. A typical routine makes 100 measurements on a module.

The diagnostic routines can find almost all-functional failures, however, the diagnostics are limited in their ability to find failures where a performance value is just out of spec. The internal voltmeter has an accuracy of approximately 2% and this is not accurate enough to measure some internal signals to determine if the specification is being met. However, these ‘out of spec’ problems are historically a small part of total instrument failures. Another limitation is there are usually only 8 points on a module where measurements can be made. These 8 points were selected to maximize the amount of circuitry that can be tested, but there is still some circuitry on most modules that cannot be tested. In general the diagnostics will not find problems with phase noise, spurs, output level accuracy, high deviation FM and fast switching.

The service documentation available with the PSG products consists of a diagnostics manual and a service manual. The diagnostics manual is needed to use the diagnostics. Its purpose is to guide the user to finding the bad module and replacing it with another module. The service manual contains schematic diagrams and uses the result of the diagnostics to guide the user in repairing the bad module to the bad component.

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