

# INTRODUCTION TO COMMUNICATION SYSTEMS

## LABORATORY II

### Amplitude Modulation

#### Introduction:

In this lab we shall investigate some elementary aspects of conventional AM, DSB-SC, and SSB signals.

#### Text References:

Sections 3.2 in *Communication Systems Engineering, (2nd ed.)* by J. G, Proakis and M. Saleh.

#### Preparation:

1. State in the most general form possible the form of a conventional AM modulated signal with sinusoidal  $m(t)$  and modulation index  $\mu$ . Sketch what the power spectrum of such a signal would be, showing explicitly how the power spectrum relates to  $\mu$ .
2. In the demodulation of DSB-SC, if the sinusoidal carrier input to the demodulator was replaced by a periodic signal at the same frequency as the carrier used in the receiver, would the receiver still work? Assume that the periodic signal has a large component at the fundamental frequency.

#### Apparatus:

- 1 - Spectrum analyzer (Anritsu MS610A[or C], or IFR 2398 Spectrum Analyzer)
- 1 - Krohn-Hite 3202 filter unit
- 1 - Rockland 2763 filter unit with at least one LP channel
- 1 - dual channel oscilloscope
- 1 - DDS function generator with AM modulation (Wavetek model 29)
- 2 - function generators (Leader LFG-1310)
- 1 - adder unit (custom lab box)
- 1 - balanced modulator (custom lab box)

#### CAUTION

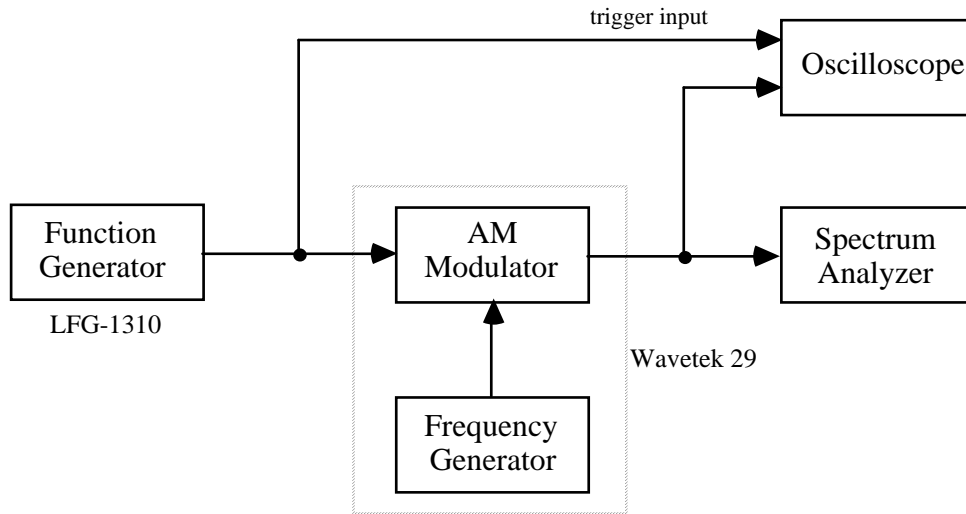
#### CAUTION

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Spectrum analyzers are very expensive, delicate and sensitive pieces of equipment which can be very easily abused. Make sure that at all times the signals you apply to the input does not exceed the maximum allowable input level noted on the front of the unit. If you are unsure of a signal level, measure it on your oscilloscope or with a voltmeter before you apply the signal to the spectrum analyzer.

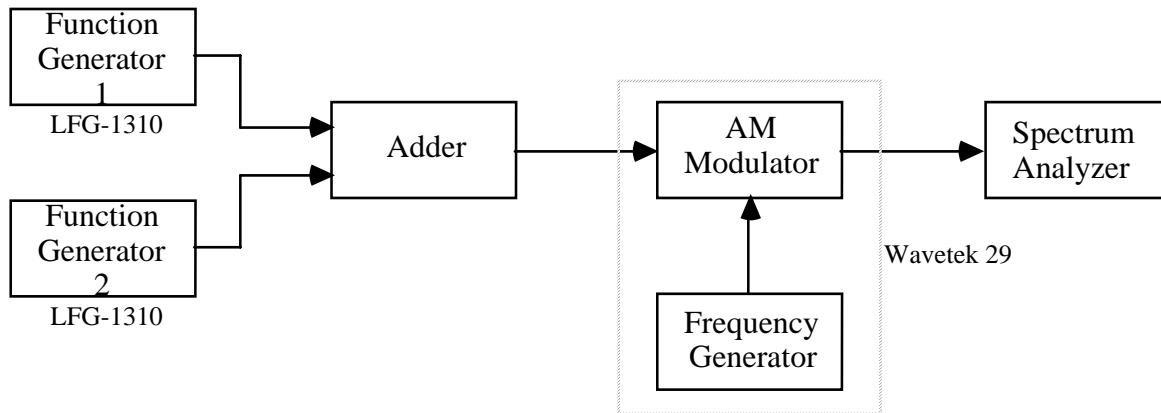
**Procedure:**

**Part I: AM Spectra**



1. Set up the above system using the Wavetek Model 29 DDS as a carrier generator and modulator. The input to the modulator is on the rear of the unit (the VCA input) when the Wavetek 29 has SOURCE =EXT VCA set in the AM menu on the Wavetek. The carrier signal is generated internally and has the frequency you set from the control panel as described in the appendix. Set this frequency to 400 kHz. With no signal applied to the VCA input, observe the modulator output on the spectrum analyzer and verify that there is simply a spectral line at 400 kHz.
2. Apply a sinusoid of approximately 20 kHz to the VCA input of the Wavetek. Adjust the signal levels of the 20 kHz sinusoid (DC offset and/or amplitude) to obtain 25%, 66.7%, and 100% modulation. In each case sketch the spectrum analyzer displays. Find the total power that is in the sidebands from the spectrum analyzer display.

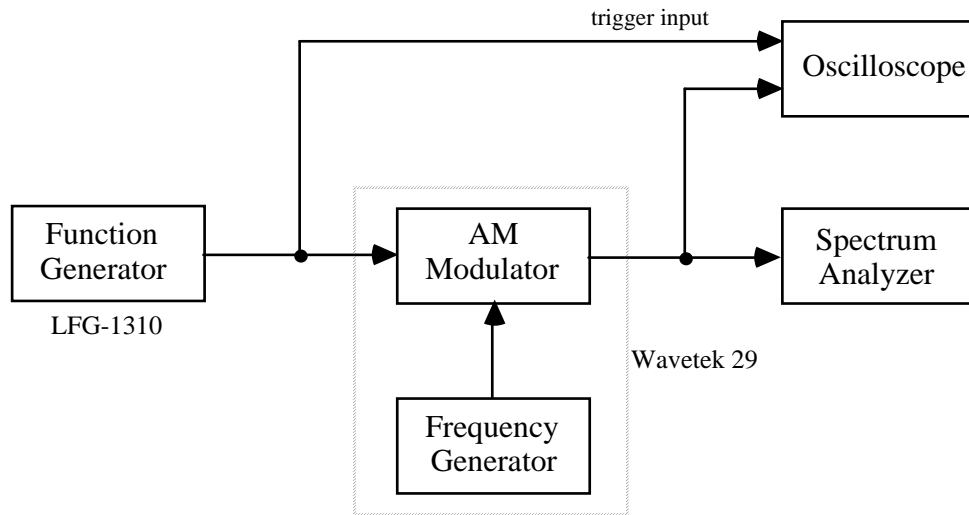
**Part II: Superposition Principle for AM**



1. Generate a 100% modulated AM signal using a 20 kHz sinusoidal modulating signal and 400 kHz carrier and observe the resulting signal on the spectrum analyzer. Repeat with a 40 kHz sinusoidal modulating signal.
2. Apply the sum of two modulating signals to the modulator and observe the spectrum analyzer display. Verify that the sidebands of the signal are the sum of the sidebands for the individual modulating signals.

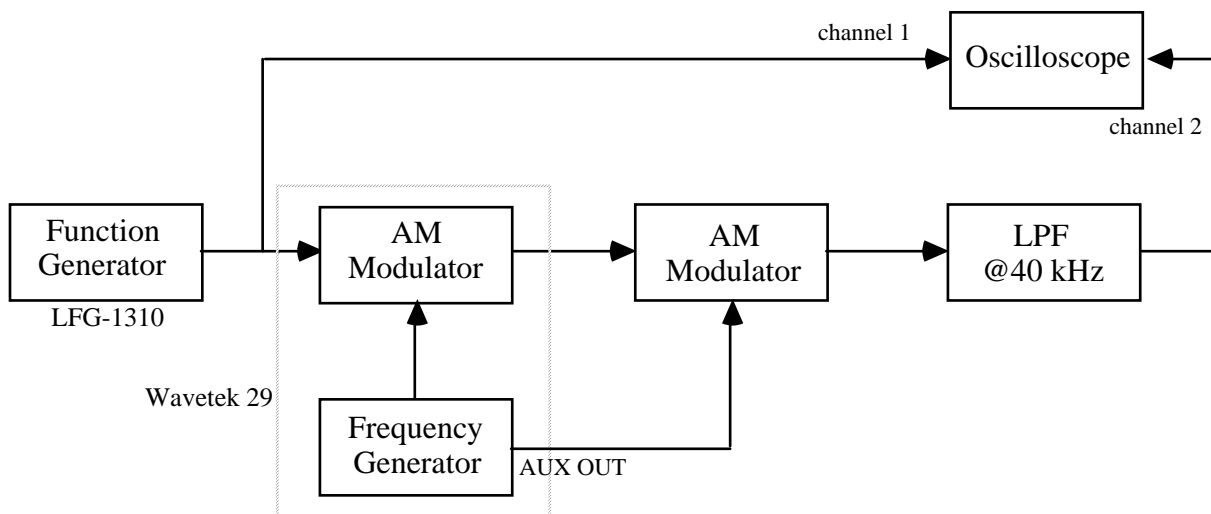
Part III: DSB-SC

A: Modulation



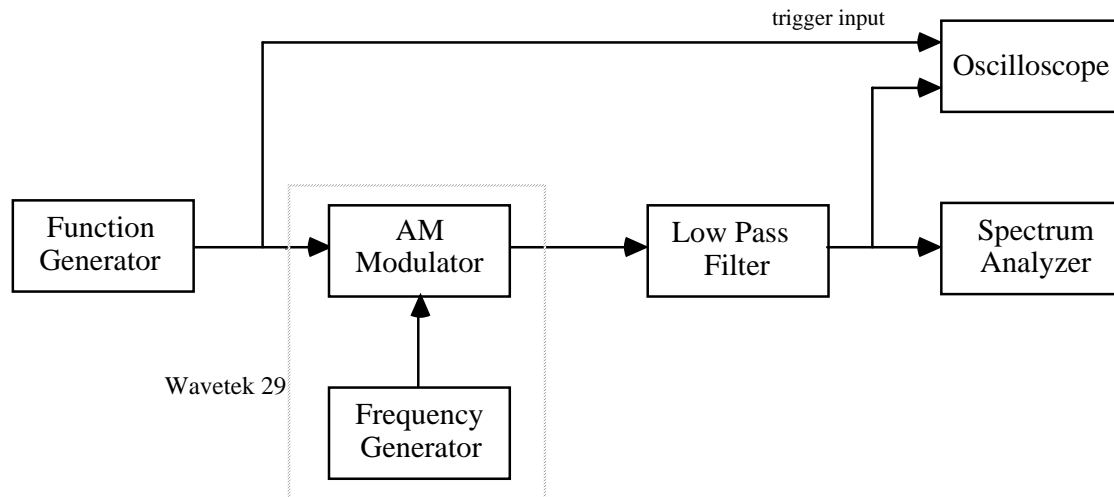
1. With the carrier frequency set to 400 kHz carrier and the LFG-1310 unit set to produce the smallest possible varying signal output to the VCA input, observe the output of the modulator on the spectrum analyzer. Adjust the DC offset of the LFG-1310 output to minimize the 400 kHz output of the modulator (to essentially zero) so as to produce a DSB-SC modulation.
2. Increase the LFG-1310's output so as to produce a 20 kHz sinusoidal modulating signal with the DC offset as above. Observe the signal on the spectrum analyzer and oscilloscope and compare to that of 100% modulated AM. Either by carefully adjusting the trigger level on the oscilloscope to catch the highest carrier peak or by a small adjustment to the modulating signal frequency, “freeze” the relative motion of the carrier and signal envelope. Note the 180° phase reversals of the carrier at the zero-crossing instants.

B: Demodulation



1. Set up the above system using a 10 kHz sinusoidal modulating signal and a 400 kHz carrier. For the second modulator, use the special lab modulators, adjusted to produce DSB-SC modulation. The carrier input to these units should be taken from the AUX OUT output on the Wavetek 29. Verify that the output of the system is a 10 kHz sinusoid. Observe the signal at the output of both modulators. Change the modulating signal to a triangular signal and a square wave to verify that the output of the system is the same as the function generator output. Explain any discrepancies.

## Part IV: SSB



1. Generate a DSB-SC signal using a 50 kHz carrier and 10 kHz modulating signal. Observe the signal on the spectrum analyzer and oscilloscope.
2. Apply the signal to the input of the filter and adjust the filter to reject one of the sidebands. The Rockland filter in LP mode is best for this. Observe the resulting signal on the spectrum analyzer and oscilloscope.
3. Decrease the modulating signal's frequency to 2 kHz and repeat the above. Why is it more difficult to reject the unwanted side-band here?
4. Verify that for the 10 kHz modulating signal and the filter adjusted per step 2, the demodulator as for DSB will demodulate the SSB signal.

## Appendix

# Wavetek Model 29 DDS Function Generator Operator's Manual (Excerpts)

## Introduction

This Programmable Function Generator uses direct digital synthesis to provide high performance and extensive facilities at a breakthrough price. It can generate a variety of waveforms between 0.1 MHz and 10MHz with a resolution of 7 digits and an accuracy better than 10ppm

### Direct digital synthesis for accuracy & stability

Direct digital synthesis (DDS) is a technique for generating waveforms digitally using a phase accumulator, a look-up table and a DAC. The accuracy and stability of the resulting waveforms is related to that of the crystal master clock.

The DDS generator offers not only exceptional accuracy and stability but also high spectral purity, low phase noise and excellent frequency agility.

### A wide range of waveforms

High quality sine, square and pulse waveforms can be generated over the full frequency range of 0.1MHz to 10MHz.

Triangle waveforms, ramp waveforms and multi-level squarewaves can also be generated but with limitations as to the maximum usable frequencies.

Variable symmetry/duty-cycle is available for all standard waveforms.

### Arbitrary waveform capability

Arbitrary waveforms can be loaded via the digital interfaces and then used in a similar way to the standard waveforms.

Up to five arbitrary waveforms of 1024 10-bit words can be stored in non-volatile memory. The waveform clock is 27.48MHz maximum.

This facility considerably expands the versatility of the instrument making it suitable for the generation of highly complex waveform patterns.

In addition, numerous "complex" waveforms are pre-defined in ROM, including commonly used waveshapes such as  $\sin(x)/x$ , exponentially decaying sine wave, etc.

### Sweep

All waveforms can be swept over their full frequency range at a rate variable between 10 milliseconds and 15 minutes. The sweep is fully phase continuous.

Sweep can be linear or logarithmic, single or continuous. Single sweeps can be triggered from the front panel, the trigger input, or the digital interfaces. Two sweep markers are provided.

### AM

Amplitude Modulation is available for all waveforms and is variable in 1% steps up to 100%. An internal AM source is incorporated. Alternatively modulation can be controlled from an external generator.

### FSK

Frequency Shift Keying provides phase coherent switching between two selected frequencies at a rate defined by the switching signal source.

The rate can be set from dc to 50kHz internally, or dc to 1 MHz externally.

### Trigger/Burst & Gated

All waveforms are available as a triggered burst whereby each positive edge of the Trigger signal will produce one burst of the carrier, starting and stopping at the phase angle specified by the start-stop phase setting.

The number of cycles in the burst can be set between 0.5 and 1023. The Gated mode turns the output signal On when the gating signal is high and Off when it is low.

Both Triggered and Gated modes can be operated from the internal Trigger Generator (0.005Hz to 50kHz) or from an external source (dc to 1 MHz).

### Waveform Hop & Noise

The generator can be set up to 'hop' between a number of different waveform set-ups either at a pre-determined rate or in response to a manual trigger.

Up to 16 different hop waveforms can be defined in terms of frequency, amplitude, function, offset and duration, which is variable in 1ms steps up to 60s. The generator can also be set to simulate random noise within the bandwidth 0.03Hz to 700kHz with adjustable amplitude and off set.

### Multiple phase-locked generators

The signals from the Clock In/Out socket and the Sync Out socket can be used to phase lock two or more generators.

This can be used to generate multi-phase waveforms or locked waveforms of different frequencies.

### Easy and convenient to use

All of the main generator parameters are clearly displayed together on a backlit LCD with 4 rows of 20 characters. Sub menus are used for the modulation modes and other complex functions.

All parameters can be entered directly from the numeric keypad. Alternatively most parameters can be incremented or decremented using the rotary encoder.

This system combines quick and easy numeric data entry with quasi-analog adjustment when required.

## Connections

### Front Panel Connections

#### MAIN OUT

This is the 50 $\Omega$  output from the main generator It will provide up to 20V peak-to-peak e.m.f. which will yield 10V peak-to-peak into a matched 500 load. It can tolerate a short circuit for 60 seconds.

Do not apply external voltages to this output.

#### AUX OUT

This is a TTL/CMOS level output synchronous with MAIN OUT Symmetry is the same as that set for the main output but the phase relationship between MAIN OUT and AUX OUT is determined by the PHASE setting specified on the TRIGger menu.

AUX OUT logic levels are nominally 0V and 5V from typically 50 $\Omega$ . AUX OUT will withstand a short- circuit.

Do not apply external voltages to this output.

#### EXT TRIG

This is the external trigger input for Trigger, Gate, Sweep, FSK and HOP operating modes. It is also the input used to synchronize the generator (as a slave) to another (which is the master).

Do not apply external voltages exceeding  $\pm 10V$ .

### Rear Panel Connections

#### CLOCK IN/OUT

The function of the CLOCK IN/OUT socket is set from the SYStem menu as follows:

INPUT	The socket becomes an input for an external clock.
OUTPUT	This is the default setting. The internal clock is made available at the socket. When two or more generators are synchronized the 'master' is set to OUTPUT and the signal is used to drive the CLOCK IN inputs of the slaves.
PHASE LOCK	When two or more generators are synchronized the slaves are set to PHASE LOCK.

As an output the logic levels are nominally 1 V and 4V from typically 50 $\Omega$ . CLOCK OUT will withstand a short-circuit. As an input the thresholds is TTL/CMOS compatible.

Do not apply external voltages to this output exceeding +7.5V or -2.5V.

**VCA IN**

This is the input socket for external voltage controlled amplitude (VCA). Input impedance is nominally 6k $\Omega$ . Apply 2.5V for 100% level change at maximum output.

Do not apply external voltages exceeding  $\pm 10V$ .

**SYNC OUT**

When two or more generators are synchronized the SYNC OUT socket on the master generator is connected to the EXT TRIG inputs of slave generators.

SYNC OUT logic levels are nominally 0V and 5V from typically 50 $\Omega$ . SYNC OUT will withstand a short-circuit,

Do not apply external voltages to this output.

**TRIG/SWEEP OUT**

The function of this output is automatically determined by the generator operating mode.

Except in sweep and HOP modes the output is that of the internal trigger generator, a fixed amplitude square-wave whose frequency is set on the TRIG or GATE menus. The rising edge of the trigger generator initiates trigger, burst, gate, etc.

In sweep mode the output is a 3-level waveform, changing from high (4V) to low (0V) at start of sweep, with narrow 1 V pulses at each marker point.

In HOP mode the output goes low on entry to each waveform step and high after the new frequency and waveshape of that step have been set.

Output levels are nominally 0V and 4V from 1k $\Omega$ . TRIG/SWEEP OUT will withstand a short-circuit.

Do not apply external voltages to this output.

**General Operation**

This section is a general introduction to the features and organisation of the function generator intended to be read before using the instrument for the first time. Detailed operation is covered in later sections starting with Main Generator Operation.

**DDS Principles**

In this instrument waveforms are generated by Direct Digital Synthesis (DDS). One complete cycle of the waveform is stored in RAM as 1024 10-bit amplitude values. As the RAM address is incremented, the waveform values are output to a Digital-to-Analog Converter (DAC) which reconstructs the waveform. Sinewaves and triangles are subsequently filtered to smooth the steps in the DAC output. The frequency of the waveform is determined by the rate at which the RAM addresses are changed. Further details of how this rate is varied, i.e. how the frequency is changed, are given later in the DDS Operation section; it is sufficient to know that at low frequencies the addresses are output sequentially but at higher frequencies the addresses are sampled. The major advantages of DDS over conventional analog generation are:

- Frequency accuracy and stability is that of the crystal oscillator.
- Frequencies can be set with high resolution from mHz to MHz.
- Low phase noise and distortion.
- Very wide frequency sweeps are possible.
- Fast phase continuous frequency switching.
- Non-standard waveforms such as multi-level squarewaves are easily generated.
- Basic arbitrary waveform capability in the same instrument.

In addition, being a digital technique, it is easier to make every parameter programmable from the keyboard, or remotely via RS232 or GPIB interfaces.

The fundamental limitation of the DDS technique is that, as the generator frequency is increased, each waveform cycle is constituted from fewer samples. This is not a problem with sinewaves which, because they are filtered, can be produced with low distortion up to the frequency limit of the generator. With DDS squarewaves and pulse waveforms the 1 clock edge uncertainty sets a practical limit to the upper frequency. However, on this instrument the generation technique changes at 30kHz (but is overridable by the user) to use a comparator driven by the DDS sinewave; this ensures jitter-free squarewaves and pulses up to the frequency limit of the generator. Ramp and staircase waveforms are, by default, unfiltered (although filtering can be selected) and therefore become degraded above the frequencies indicated in the Specification; all waveforms are, however, available up to the maximum frequency of the generator.

## Switching On

The power switch is located at the bottom left of the front panel.

At power up the generator displays the installed software revision while loading its RAM with waveforms; if an error is encountered the message "SYSTEM RAM ERROR, BATTERY FLAT?" will be displayed, see the Warnings and Error Messages section.

Loading takes a few seconds, after which the Main menu is displayed, showing the generator parameters set to their default values, with the MAIN OUT set off. Refer to the System Menu section for how to change the power up settings to either those at power down or to any one of the stored settings.

Change the basic generator parameters as described in the Main Generator Operation section and switch the MAIN OUT on with the OUTPUT key; the ON lamp will light to show that the output is on. Note that AUX OUT, CLOCK OUT, etc. are always running and are not switched by the OUTPUT key.

## Display Contrast

All parameter settings are displayed on the 20 character x 4 row backlit liquid crystal display (LCD). The contrast may vary a little with changes of ambient temperature or viewing angle but can be optimised for a particular environment by using the front panel contrast control. Insert a small screwdriver or trimmer tool through the adjustment aperture marked LCD and rotate the control for optimum contrast.

## Keyboard

The keys can be considered in 7 groups: FUNCTION keys permit direct selection of the waveform function.

Repeated presses of each of the 3 keys steps the function selection through each of the 2 or 3 choices associated with that key; the current selection is indicated by the illuminated lamp. Pressing a different key selects the function last selected with that key. In this way it is therefore possible to select between, for example, sine, square and triangle with single key presses, or between positive pulses and negative pulses, etc.

- SET keys permit direct selection of the four main generator parameters shown on the Main menu of the display, ready for value entries from the NUMERIC/UNIT keys.
- NUMERIC/LINIT keys permit direct entry of a value for the parameter currently selected; parameter selection is either directly (by the SET keys) for the main parameters, or by moving the cursor to the appropriate parameter in other menus. Thus to set a new frequency of 100kHz, for example press FREQ/PER, 1, 0, 0, kHz; or to change symmetry to 40%, press SYMMETRY, 4, 0, %.
- FIELD and DIGIT keys are used, together with the ROTARY CONTROL, to edit parameters on the current menu. Their use is explained more fully in the 'Principles of Editing' section below.
- MODE keys are used both to directly switch the respective mode (TRIG, GATE, AM, etc.) on or off and to select the menus for setting up these special functions. Alternate presses of a MODE key will turn the function on or off; when on the associated lamp is lit. Pressing the blue EDIT key followed by a MODE key displays the edit menu for that mode; the associated lamp flashes while the edit menu is displayed.
- UTILITIES keys give access to the STORE, RECALL and REMOTE parameter menus; the MAN/SYNC key is used for manual triggering and synchronizing two or more generators when suitably connected together.
- Lastly, the ENTER, ESCAPE, and CE (Clear Entry) keys have self-explanatory functions.

Numeric entries are automatically confirmed when the appropriate unit key (Hz, kHz, MHz, etc.) is pressed but ENTER can be used to enter a number in the parameter's basic units or to confirm entries with fixed units (e.g. phase) or no units (e.g. burst count). It is also used to confirm certain options when prompted.

Pressing ESCAPE returns a setting being edited to its last value; a second press (when appropriate) will return the display from an edit menu to the Main menu.

CE (Clear Entry) undoes a numeric entry digit by digit.

Further explanations will be found as appropriate in the detailed descriptions of the generator's functions.

## Principles of Editing

FIELD and DIGIT keys are used, together with the rotary control, to edit parameters shown on the current menu. The Main menu shows all the basic generator parameters and is the one displayed unless editing of a special function has been selected. These edit menus are accessed by pressing the blue EDIT key, followed by the appropriate MODE key or a numeric key which has a secondary function printed in blue.

FIELD keys move the flashing edit cursor forward or backwards from one editable field to the next; all the digits of a numeric parameter value are treated as a single field. When the parameters of a particular function occupy two or more pages of the display, e.g. the sweep mode parameters, the further pages are indicated by MORE-> shown in the display and the FIELD keys are also used to step between the end of one page and the start of another, and vice-versa. The attributes of the flashing edit cursor can be changed by the user if desired, see SYStem Menu section.

DIGIT keys operate in more than one mode. When a numeric parameter value field is selected by the FIELD keys, DIGIT keys step the edit cursor forward or backwards through the digits of the field. When the edit cursor is positioned in a parameter name (e.g. **FREQ**) pressing either digit key will step the parameter through each of the alternative forms in which a value may be entered (e.g. **FREQ** is changed to **PERiod**); the parameter numeric value and units change accordingly. Note that where there is no alternative form for the parameter (e.g. **SYMMETRY**) the edit cursor cannot be stepped into that field. When the edit cursor is positioned in a parameter selection field (e.g. **SOURCE = on** on the **TRIG** menu), the DIGIT keys step through all possible choices for that parameter (e.g. **SOURCE = TGEN**, **SOURCE = EXT**, etc.) Lastly, when the edit cursor is positioned in the units field of a parameter value, the DIGIT keys increment or decrement the numeric value of the parameter by a factor of 10 each press; the units change each time the display autoranges.

The **ROTARY CONTROL** works as follows. With the cursor in any field other than a numeric value field turning the control acts in exactly the same way as pressing the DIGIT keys. With the edit cursor positioned anywhere in a parameter numeric field, turning the control will increment or decrement the value; the step size is determined by the position of the edit cursor within the numeric field.

Thus for **FREQ = 1.00000 MHz** rotating the control will change the frequency in 1 kHz steps. The display will auto-range up or down as the frequency is changed, provided that autoranging permits the increment size to be maintained; this will in turn determine the lowest or highest setting that can be achieved by turning the control. In the example above, the lowest frequency that can be set by rotating the control is 1 kHz, shown on the display as

**FREQ = 1.000000 kHz**

This is the limit because to show a lower frequency the display would need to autorange below 1 kHz to

**FREQ = xxx.xxx Hz**

in which the most significant digit represents 100Hz i.e. the 1 kHz increment would be lost. If however, the starting setting had been

**FREQ = 1.000000 MHz**

i.e. a 100 Hz increment, the display would have autoranged at 1 kHz to

**FREQ = 900.0000 Hz**

and could then be decremented further right down to

**FREQ = 000.0000 Hz**

without losing the 100 Hz increment.

Turning the control quickly will step the numeric values in multiple increments.

## Main Generator Operation

When first switched on, and at all subsequent power-ups unless specified otherwise on the **SYSTEM** menu, the generator will be set to the factory defaults, with the output off. The basic parameters can be set from the **Main** menu as described below.

### Main Generator Parameters

#### Frequency

```

FREQ=10.00000kHz
VhiZ=+20.0 Vpp 50Ω
DC=+0.00mV (+0.00mV)
SYM=50.0% (50.0%)

```

With the flashing edit cursor anywhere on the first line of the **Main** menu the frequency can be changed directly from the keyboard by entering the number and appropriate units only, e.g. 1kHz can be set by entering 1, kHz or •, 0, 0, 1, MHz or 1, 0, 0, 0, Hz, etc. However, the display will always show the entry in the most appropriate engineering units, in this case 1.000000kHz. By default, the maximum settable frequency for triangle, ramp, staircase and arbitrary waveforms is 100 kHz and an error message will be given if an attempt is made to enter a higher frequency with one of these waveforms selected, see **Warning and Error Messages** section. This frequency limit can be switched off, see **'Frequency Stop'** in the **Waveform Generation Options** section, although signal quality for these waveforms will deteriorate progressively as the frequency increases, as discussed in the **DDS Principles** section. If this cursor is not already in a top line field it is first necessary to press the **FREQ/PER** key before making the number and unit entry. Note that this always returns the cursor to the parameter name field which can then be alternated between **FREQ** and **PERiod** with successive presses of either DIGIT key, or by turning the rotary control.

```

PER=100.0000us
VhiZ=+20.0 Vpp 50Ω
DC=+0.00mV (+0.00mV)
SYM=50.0% (50.0%)

```

When PER= shows in the display instead of FREQ=, the frequency can be set in terms of a period; enter the number and units (ns,  $\mu$ s, ms or s) in the same way as for frequency. Note that the precision of a period entry is restricted to 6 digits; 7 digits are displayed but the last significant one is always zero. The hardware is always programmed in terms of frequency; when a period entry is made the synthesised frequency is the nearest equivalent value that the frequency resolution and a 6-digit conversion calculation gives. If the frequency is displayed after a period entry the value may differ by a digit from the expected value because of these considerations. Further, once the setting has been displayed as a frequency, converting back again to display period will give an exact 6-digit equivalent of the 7-digit frequency, but this may differ, by a digit, from the period value originally entered. If the edit cursor is moved to the numeric field, turning the rotary control will increment or decrement the numeric value in steps determined by the edit position within the field. The FIELD keys move the cursor to the field and the DIGIT keys move it within the field; this is more fully explained in the Principles of Editing section. Lastly, with the edit cursor in the units field, pressing the DIGIT keys or turning the rotary control will change the value in decade increments; the decimal point will move and/or the units will change as appropriate. Full 7-digit precision is maintained as the value is decremented until the 0- 1 mHz resolution limit of the instrument is reached; values which would have had least significant bits  $<0.1$  mHz are truncated with further decrements and the precision is consequently lost when the number is incremented again.

### Output Level

The second line of the Main menu permits the output level to be set in terms of VhiZ (open circuit voltage) or V (potential difference into a matched load) or dBm (referenced to the specified source impedance). Both VhiZ and V can be set in terms of peak-peak volts (Vpp) or r.m.s. volts (Vrms). Note that in both cases the true peak-peak or r.m.s. values are shown for the selected waveform, even an arbitrary waveform. However, in the case of Vrms the DC Offset (see next section) is ignored in the calculation and must be taken into consideration by the user if the DC Offset is non-zero.

```

FREQ=10.00000kHz
VhiZ=+20.0 Vpp 50 $\Omega$ 
DC=+0.00mV (+0.00mV)
SYM=50.0% (50.0%)

```

The desired form of the output level display can be selected while the edit cursor is in the parameter name field by stepping through all the options with the DIGIT keys or the rotary control; bring the cursor to the parameter name field first, if necessary, by pressing AMPL, or by using the FIELD keys.

With the appropriate parameter form selected, the value is entered as a number followed by units, e.g. 100mV can be entered as 1, 0, 0, mV or \*, 1, V etc. The software acts intelligently in certain situations; for example, even if VhiZ or V is the selected parameter form, entering a number followed by the dBm key will cause the number to be entered as dBm. Similarly, with dBm as the selected parameter form, entering a number followed by V or mV will cause the number to be entered as V=Vrms. 0dBm is 1 mW into the specified impedance; low signal levels are specified by using the +/-key to enter negative dBm. See also the last paragraph of this section for the use of the +/-key for output inversion.

Moving the edit cursor to the numeric field permits the set value to be varied by the rotary control in steps determined by the cursor position within the field. The FIELD keys move the cursor to the field and the DIGIT keys move it within the field; this is explained more fully in the Principles of Editing section.

Moving the edit cursor to the units field permits the numeric value to be changed in decade steps by the DIGIT keys or rotary control; the decimal point will move and/or the units will change as appropriate. Further increments are inhibited if the next decade step would take the value above the maximum level or below the minimum level. Decade stepping with the DIGIT keys or rotary control is also inhibited when the level is displayed in dBm.

Wherever the cursor is positioned on the second line of the display, alternate presses of the +/-key will invert the MAIN OUT output; if DC OFFSET is non-zero, the signal is inverted about the offset. The one exception to this is if the output level is specified in dBm; since low signals are specified in -dBm, the - sign is interpreted as part of a new output level entry and not as a command to invert the signal. The output level must be shown as a VhiZ or V value for the key to operate as a signal invert key.

If an amplitude change is made which involves switching the attenuator, the output is switched off for 45ms while the change is made to prevent any transients appearing at the output.

### Output Impedance

The impedance of the MAIN OUT output is selected in the last field of the second line. Move the edit cursor to this field and use the DIGIT keys or rotary control to toggle between 50 $\Omega$  and 600 $\Omega$ . The output level is unchanged but the displayed value in dBm will change because the 0dBm reference level (1 mW into the specified impedance) changes with the impedance.

### DC Offset

The DC Offset is set on the third line of the Main menu. With the cursor anywhere in the third line the DC offset can be changed directly from the keyboard by entering the number and appropriate units, e.g. 100mV can be set by

entering 1, 0, 0, mV or \*, 1, V, etc. If the cursor is not already in the third line of the display it is first necessary to press the DC OFFSET key, to position the cursor, before making the number and unit entry. Note that, unlike the FREQ= or VhiZ= parameter fields, the cursor does not move into the DC OFFSET name because it has no alternative.

With the edit cursor in the numeric field, turning the rotary control will increment or decrement the numeric value in steps determined by the edit cursor position within the field. The DC OFFSET or FIELD keys move the cursor to the field and the DIGIT keys move it within the field; this is more fully explained in the Principles of Editing section. Because DC offset can have negative values, the rotary control can take the value below zero; although the display may autorange to a higher resolution if a step takes the value close to zero, the increment size is maintained correctly as the offset is stepped negative. For example, if the display shows

```
DC = +205. mV
```

with the cursor in the most significant digit, the rotary control will decrement the offset in 100mV steps as follows:

```
DC = +205.mV
```

```
DC = +105.mV
```

```
DC = +5.00 mV
```

```
DC = -95.0 mV
```

```
DC = -195. mV
```

The +/- key can also be used at any time to set the offset value negative; alternative presses toggle the sign between + and -. Alternatively the sign of the offset can be changed as part of the entry of a new value, e.g. if the offset is +2.00V it can be changed to -100mV by pressing +/- 1, 0, 0, mv. The actual DC offset at the MAIN OUT socket is attenuated by the fixed-step output attenuator when this is in use. Since it is not obvious when the signal is being attenuated the actual offset is shown in brackets as a non-editable field to the right of the set value. For example, in the display below, the pk- pk output is not attenuated by the fixed attenuator and the actual DC offset (in brackets) is the same as that set.

```
FREQ=10.00000kHz
VhiZ=+2.50 Vpp 50Ω
DC=+150.mV (+150.mV)
SYM=50.0% (50.0%)
```

If the output level is now reduced to 250mV pk-pk, which introduces the attenuator, the actual DC offset changes by the appropriate factor:

```
FREQ=10.00000kHz
VhiZ=+250.mVpp 50Ω
DC=+150.mV (+15.1mV)
SYM=50.0% (50.0%)
```

The above display shows that the set DC offset is +150mV but the actual offset is +15.1 mV. Note that the actual offset value also takes into account the true attenuation provided by the fixed attenuator, using the values determined during the calibration procedure. In the example displayed the output signal is 250mV pk-pk exactly and takes account of the small error in the -20dB fixed attenuator; the offset is 15.1 mV exactly, taking account of the effect of the known attenuation (slightly less than the nominal -20dB) on the set offset of 150mV.

Whenever the set DC offset is modified by a change in output level in this way a warning message that this has happened will be displayed. Similarly, because the DC offset plus signal peak is limited to  $\pm 10V$  to avoid waveform clipping, a warning message will be displayed. This is explained more fully in the Warnings and Error Messages section.

## DC Output

The DC Offset control can be used to provide an adjustable DC output level if the waveform is off - the recommended set-up is as follows:

Select GATE edit mode and set the SOURCE to MAN/REMOTE. Exit edit mode and turn on GATE mode with the GATE key. Provided that GATE mode is not triggered, the MAIN OUT will now remain at the level set by the DC Offset control.

On the main menu set the output level to 1Vpp; this ensures that the software does not warn of clipping (output level too high) and that the output attenuator is not switched in (which would also attenuate the DC Offset). With the cursor in the DC Offset field the MAIN OUT can now be adjusted over the range  $\pm 10V$  (open circuit).

## Symmetry

Pressing the SYMMETRY key moves the flashing edit cursor directly to the symmetry numeric field on the bottom line of the display. This is the only field that can be edited; the bracketed field on the right-hand side shows the actual symmetry which might differ from that set if the set value is outside that permitted for the selected frequency and waveform combination, see Specification section. For example, in the display below the frequency is set to 100kHz and a squarewave is selected.

```
FREQ=100.0000kHz
VhiZ=+20.0 Vpp 50Ω
DC=+0.00mV (+0.00mV)
SYM=90.0% (80.0%)
```

The symmetry is set to 90% but the actual symmetry is 80%, the limit for squarewaves and pulse waveforms above 30kHz.

The flashing cursor can be moved within the field using the DIGIT keys; turning the rotary control will then increment or decrement the setting in steps determined by the position of the cursor in the field.

Should the symmetry be set outside the permitted range for the selected frequency and waveform combination a warning message will be shown on the display, see Warnings and Error Messages section below.

## Warning and Error Messages

Two classes of message are displayed on the screen when an illegal combination of parameters is attempted.

WARNING messages are shown when the entered setting causes some change which the user might not necessarily expect. Examples are:

1. Changing VhiZ from 2.5Volts pk-pk to 250mV pk-pk brings in the step attenuator; if a nonzero offset has been set then this will now be attenuated too. The message 'DC OFFSET CHANGE BY OUTPUT LEVEL' will be shown temporarily on the screen but the setting will be accepted; in this case the actual, attenuated, offset will be shown in brackets to the right of the set value.
2. With the output level set to 10V pk-pk, increasing the DC offset beyond  $\pm 5V$  will cause the message 'DC OFFSET + LEVEL MAY CAUSE CLIPPING'. The offset change will be accepted (producing a clipped waveform) and the user may then choose to change the output level or the offset to produce a signal which is not clipped.
3. With 100kHz squarewave selected, increasing symmetry beyond 80% will cause the message 'SYMMETRY TOO WIDE FOR FUNC/FREQ' to be displayed. The setting will be accepted but the actual symmetry will be limited to 80% as shown in the bracketed field beside the setting. If this out-of- specification setting is changed by reducing the frequency below 30kHz or by changing the waveform then the warning 'SYMMETRY CHANGED BY FUNC/FREQ' is displayed.

ERROR messages are shown when an illegal setting is attempted, most generally a number outside the range of values permitted. In this case the entry is rejected and the parameter setting is left unchanged. Examples are:

1. Entering a frequency of 100 MHz with any waveform selected, or 1 MHz with triangle selected, etc. The error message 'FREQUENCY/PERIOD VAL OUT OF RANGE' is shown.
2. Entering a VhiZ of 25V pk-pk. The error message 'MAX OUTPUT LEVEL EXCEEDED' is shown.
3. Entering a DC offset of 20V. The error message 'MAX DC OFFSET EXCEEDED' is shown.

The messages are shown on the display for approximately two seconds. The last two messages can be viewed again by pressing the blue EDIT key followed by MSG (the 0 number key). Each message has a number and the full list appears in Appendix 1, together with some further explanation where the message is not entirely self-explanatory.

The default set-up is for all warning and error messages to be displayed and for a beep to sound with each message. This set-up can be changed on the ERRor menu, accessed by pressing the blue EDIT key followed by ERRor key (the 2 number key). The ERRor menu is shown below:

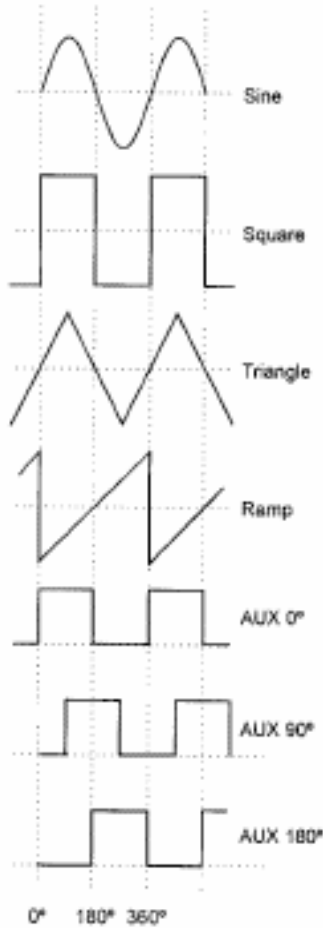
```
ERROR BEEP=ON
ERROR MESSAGE=ON
WARNING BEEP=ON
WARNING MESSAGE=ON
```

The flashing cursor can be moved through each of the four editable fields in turn using the FIELD keys. The field can then be toggled between ON and OFF, using the DIGIT keys or rotary control, to create the desired setting. If the new setting is required for future use it should be saved by changing the POWER UP= setting on the SYStem menu to POWER UP=POWER DOWN, see System Menu section.

## Auxiliary Output

AUX OUT is a TTL/CMOS level output synchronous with MAIN OUT and with the same symmetry. However, the phase of the AUX OUT can be varied with respect to the MAIN OUT by changing the PHASE setting on the TRIGger edit menu.

**Auxiliary Output Phase**



The convention adopted for phase in this instrument is illustrated in the diagram. 0° is always the first data point in waveform memory. On symmetrical waveforms 0° is the rising edge 'zero-crossing' point for sine, square, triangle and pulse waveforms; 0° is the start point of ramps, staircase and arbitrary waves. When the phase is set to 0° the rising edge of the AUX OUT squarewave is at 0° too. When the phase is set to a positive value, e.g. +90°, the AUX OUT squarewave follows MAIN OUT by 90°, when the phase is set to a negative value AUX OUT leads MAIN OUT

The phase is set by pressing the blue EDIT key followed by TRIG to select the trigger edit menu; the edit cursor is then moved to the PHASE field using the FIELD keys. PHASE can be entered directly from the keyboard, using the +/- key to change the sign if necessary, or by rotary control.

Above 30kHz the AUX OUT accompanying sine, triangle, square and pulse waveforms is automatically switched such that it is derived from the comparator (driven by the DDS sinewave) used to generate higher frequency MAIN OUT squarewaves and pulses; see the DDS Principles section for further information. This ensures a jitter-free AUX OUT signal up to the maximum frequency of the generator but means that phase shifting between MAIN OUT and AUX OUT is not then possible.

However, this constraint can be removed by changing the setting on the OPTions menu from AUX OUTPUT=AUTO to AUX OUTPUT=LOW FREQ; the AUX OUT signal then continues to be generated independently, with phase adjustable with respect to the MAIN output, although the 1 clock (36ns) jitter will become increasingly significant at higher frequencies. Changing AUTO settings is described more fully in the next section, Waveform Generator Options.

The AUX OUT signal accompanying ramp, staircase and arbitrary waveforms is, by default, always generated independently; phase shift is adjustable across the frequency range but again clock jitter becomes increasingly significant at higher frequencies.

**Waveform Generation Options**

A number of parameters are, by default, switched automatically either when the frequency is set above 30kHz or when the operating mode is changed such that the best overall performance is achieved across

the whole generator frequency range; see the DDS Principles section for further details of the 30kHz changeover. In addition, triangle, ramp, staircase and arbitrary waveforms are inhibited from being set above 100kHz, to ensure that they are not used accidentally at frequencies where the waveshape is noticeably deteriorating. In all cases, however the default choice can be overridden by the user by changing the setting on the OPTions menu.

```
SQWAVE GEN=AUTO
FILTER=AUTO
AUX=AUTO FSTOP=ON
SWEEP TGEN OUT=AUTO
```

The OPTions edit menu shown above is selected by pressing the blue EDIT key followed by OPTN (the shifted function of 1). The following descriptions, grouped together in this section for reference convenience, should be read in conjunction with the main explanations of the appropriate parameter elsewhere in this manual. Each parameter is altered by moving the edit cursor to the appropriate field with the FIELD keys and using the DIGIT keys or rotary control to change the setting.

**Squarewave Generation**

In LOW FREQUENCY mode the squarewave and pulse waves are generated digitally; in this way precision squarewaves can be generated down to very low frequencies without the edge uncertainty that would be associated with conventional ramp-and-comparator techniques. Above approximately 27kHz (clock frequency, 27.487MHz, ÷1024) the waveforms are sampled and the 1 clock (36ns) uncertainty introduces edge jitter which becomes increasingly significant at higher frequencies. In HIGH FREQUENCY mode the squarewave and pulses are derived from the output of a comparator driven by the DDS generated sinewave. The sinewave is, by default, filtered and jitter-free; the high frequency squarewave and pulse waveforms are thus jitter free too.

In AUTO mode (the default) the generation of squarewave and pulse waveforms is automatically switched from low to high frequency mode when the frequency exceeds 30kHz. However, when these waveforms are used in sweep and FSK modes, over a frequency range which includes the 30kHz changeover point, the generation mode will not

change even though AUTO is selected. Instead, the mode in use before sweep or FSK are turned on is maintained across the frequency range; this can of course be overridden by selecting either high or low frequency mode on the Options menu, as described above.

### Filter

The generator contains a 7-stage elliptical filter which exhibits a sharp cut-off beyond the maximum generator frequency, reducing intermodulation spurs and clock harmonics to a very low level. With the default condition of FILTER=AUTO set on the Option menu, the filter is switched in automatically for sine, triangle, high frequency squarewave and high frequency pulse waveforms (although the squarewave and pulse waveforms themselves do not pass through the filter); the filter is automatically switched out for low frequency squarewave and pulses, ramp, staircase and arbitrary waveforms because of the degrading effect it has on fast transitions in the waveform. However, for all these waveforms the filter can be set to be always on (FILTER=ON) or always off (FILTER=OFF); this has the advantage that, for example, an arbitrary waveform with an essentially sinusoidal content can be output with the filter on.

When Noise is selected, see Special Waveforms section, this 7-stage filter is always off, whatever the FILTER = setting, and a simple 700kHz low pass RC filter is switched in instead.

### Auxiliary Output

When sine, triangle, squarewave or pulse waveforms are selected and with AUX OUTPUT=AUTO the auxiliary output squarewave generation switches automatically at 30kHz from DDS generation to a signal derived from a comparator driven by the DDS sinewave; the advantages of this approach are the same as those detailed previously in the Squarewave Generation section. However, as detailed in the Auxiliary Output Phase section, the high frequency generation mode has the disadvantage that a phase difference can no longer be set between AUX OUT and MAIN OUT. The automatic switchover at 30kHz can therefore be overridden by setting AUX OUTPUT=LOW FREQUENCY, to maintain it in true DDS mode, or AUX OUTPUT=HIGH FREQUENCY to lock it in high frequency mode. With AUX OUTPUT=AUTO there is no automatic mode changeover if ramp, staircase or arbitrary waveforms are selected; high frequency mode can however be forced by setting AUX OUTPUT=HIGH FREQ.

Note that there is some second order interaction between the Squarewave Generation, Filter and Auxiliary Output settings which demand a little thought before deviations from the default conditions are defined. For example, if SQWAVE GEN and AUX OUTPUT options are set to AUTO but FILTER is set to OFF the edges of both the MAIN OUT and AUX OUT squarewaves will exhibit some jitter at high frequencies (e.g. 1 MHz) because the sinewave driving the comparator from which both are derived will itself be jittery.

### Frequency Stop

In the default mode of FSTOP=ON the maximum settable frequency for triangle, ramp, staircase and arbitrary is limited to 100kHz. Error messages will be shown if either an attempt is made to enter a frequency above 100kHz while one of these waveforms is selected, or if an attempt is made to select one of these waveforms with the frequency already set above 100kHz. This mode is useful in ensuring that frequencies are not accidentally set too high for waveforms whose quality will deteriorate above 100kHz. With FSTOP=OFF there are no frequency limits on these waveforms; waveform quality will however deteriorate progressively as the frequency increases for certain waveforms, as discussed in the DDS Principles section.

### Trigger/Sweep Output

With SWEEP/TGEN=AUTO the function of the rear panel TRIG/SWEEP OUT socket changes automatically when the operating mode is changed between Sweep, HOP and any other mode; the two functions of this output are described in the Connections section.

When SWEEP/TGEN=SWEEP is set the TRIG/SWEEP OUTput is always in the Sweep mode, if sweep is operational, or HOP mode if HOP is on; when SWEEP/TGEN=TRIG the TRIG/SWEEP OUTput always outputs the internal trigger generator signal. Note that, except when using the internal trigger generator in Trigger, Gate, FSK or AM modes, this signal is not synchronized with the main generator.

### Triggered Burst and Gate

In Burst mode a defined number of cycles are generated following each trigger event. This mode is edge triggered.

In Gated mode the generator runs whenever the gating signal is high. This mode is level sensitive.

Both Burst and Gated modes can be controlled by either the internal trigger generator, an external trigger input, by the front panel MAN/SYNC key or by remote control.

### Internal Trigger Generator

The internal trigger generator divides down a crystal oscillator to produce a 1:1 square-wave with a period from 0.02ms (50kHz) to 200s (0.005Hz). Generator period entries that cannot be exactly set are accepted and rounded

up to the nearest available value, e.g. 0.109ms is rounded to 0.12ms. The generator output is available as a TTL level signal at the rear panel TRIG/SWEEP OUT socket.

In Burst mode the rising edge of each cycle of the trigger generator is used to initiate a burst; the interval between bursts is therefore 0.02ms to 200s as set by the generator period.

In Gated mode the output of the main generator is gated on while the trigger generator output is high; the duration of the gate is therefore 0.01 ms to 100s in step with trigger generator periods of 0.02ms to 200s.

### External Trigger Input

External trigger or gate signals are applied to the front panel EXT TRIG input which has a TTL level (1.5V) threshold. In Triggered Burst mode the input is edge sensitive; the rising edge of each external trigger initiates the specified burst. In Gated mode the input is level sensitive; the output of the main generator is on while the gate signal is high (>1.5V).

The minimum pulse width that can be used with the EXT TRIG input is 50ns and the maximum repetition rate is 1 MHz. The maximum signal level that can be applied without damage is  $\pm 10V$ .

### Triggered Burst

Triggered Burst mode is turned on and off with alternate presses of the TRIG key; the lamp beside the key lights when triggered mode is on. The triggered mode parameters (trigger

source, internal trigger generator, burst count and start/stop phase) are all set from the trigger edit menu which is selected by pressing the blue EDIT key followed by the TRIG key. When

trigger edit is selected the lamp beside the TRIG key flashes to show edit mode regardless of whether triggered burst operation is currently selected to be on or off.

```
SOURCE=EXT
TGEN=1.00ms 1.000kHz
BURST COUNT= 0001
PHASE=+000° (+000°)
```

### Trigger Source

With the edit cursor in the SOURCE field of the trigger edit menu, the DIGIT keys or rotary control can be used to select EXTERNAL, MAN/REMOTE, or internal Trigger GENERATOR as the trigger source.

With the source set to EXTERNAL, the specified burst is triggered by the rising edge of a trigger signal applied to the EXT TRIG input, see External Trigger Input section. With the source set to MAN/REMOTE, a burst can be initiated by pressing the front panel MAN/SYNC key or by the appropriate command via the RS232 or GPIB interfaces.

With the source set to TGEN, the burst is triggered internally as described in the Internal Trigger Generator section. The period of the internal generator is set in the TGEN field on the second line of the edit menu. With the cursor in the numeric field the DIGIT keys will move the cursor within the field and the rotary control will change the value in increments determined by the cursor position; with the cursor in the units field the DIGIT keys or rotary control will change the value in decade increments. Direct keyboard entries (number plus units) will be accepted with the cursor in either field. Beside the generator period value the equivalent frequency is shown; this is for information only and is not an editable field.

Because the internal trigger generator can be used by the trigger, gate, FSK and AM functions and can be set from their respective edit menus, an information field is displayed in brackets beside TGEN when this is selected as the source. This field will show [FREE] when TGEN is not used elsewhere, or any of the letters [G,F,A,T] to indicate that the generator is currently set as the source on the GATE, FSK, AM, or TRIG menus respectively, in addition to the menu currently displayed.

### Burst Count

The number of complete cycles in each burst following the trigger is set with the edit cursor in the BURST COUNT field. Entries can be made direct from the keyboard or by rotary control; the burst range is 1 to 1023 with a resolution of 1 cycle or 0.5 to 511.5 with a resolution of 0.5 cycles. The first cycle starts, and the last cycle stops, at the phase set in the PHASE field.

### Start/Stop Phase

The start and stop phase of the triggered burst is set in the PHASE field. The PHASE field actually sets the phase of the Auxiliary Output and it is from this output that control of the start and stop point of the main generator is derived; the rising edge of the AUX OUT signal, which can be phase shifted with respect to the MAIN OUT, determines the start and stop point of the main waveform burst. Consequently, the conditions under which the Auxiliary Output phase shift is constrained, and which are fully explained in that section, all apply to start/stop phase. For example, the start/stop phase of sine and triangle waveforms cannot be adjusted for main output frequencies above 30kHz unless the AUX OUTPUT field on the Options menu is set to LOW FREQUENCY

generation mode because only in this mode does the AUX OUT continue to be phase shifted with respect to MAIN OUT

Because the phase control signal is derived from the Auxiliary Output waveform further considerations apply as the main generator frequency is increased. With AUX OUTPUT= LOW FREQ on the Options menu phase shift control is still available above 30kHz but real hardware delays become increasingly significant such that the start/stop phase increases for no change in phase setting; this shift is caused by the delay between AUX OUT and MAIN OUT becoming more significant and by the delays in the burst count and phase control circuit themselves. These delays can be equivalent to say a +45° phase shift at 1 MHz; however, by 'backing off' the required phase shift by -45° the desired condition can still be achieved. At the same time, however, the fewer samples making up each cycle of the waveform means that the start/stop point becomes an uncertain 'band' which is 1 clock wide.

Note that these effects apply even when the phase is set to 0°; at frequencies approaching 10MHz the phase shift can be 90° or more and the uncertainty band becomes wide. Because this effect is seen at 0° phase it is also evident when AUX OUTPUT is in HIGH FREQUENCY mode, i.e. when there is no phase control. In fact, because the AUX OUT signal is derived from the filtered DDS sinewave in this mode the filter adds further phase delay, creating even longer phase shifts at a given frequency than are evident with AUX OUTPUT in LOW FREQUENCY mode.

In summary, phase errors and uncertainty will increase as the main frequency is increased above 30kHz, even with 0° phase set. However, stop/start phase control can be used, with care, to much higher frequencies by 'backing-off' the phase to compensate for the hardware delays.

## Gated Mode

Gated mode is turned on and off with alternate presses of the GATE key; the lamp beside the key lights when gate mode is on. The selection of the gate source signal is made from the gate edit menu which is selected by pressing the blue EDIT key followed by the GATE key. when gate edit is selected the lamp beside the GATE key flashes to show edit mode regardless of whether gate operation is currently selected to be on or off.

```
SOURCE=EXT
TGEN=1.00ms 1.000kHz
```

## Gate Source

With the edit cursor in the SOURCE field of the gate edit menu, the digit keys or rotary control can be used to select EXTERNAL, MAN/REMOTE, or Trigger GENERATOR as the gate source. In all cases, when the gate condition is true, the main generator signal is gated through to the MAIN OUT socket. Since the main generator is free-running and not synchronized with the gate source the start and stop phase of the waveform is entirely arbitrary; there will be an instantaneous transition from/to the DC Offset level to/from the current waveform phase at the start/stop of the gating period.

With the source set to EXTERNAL, the generator waveform is gated on while the external signal applied to the EXT TRIG input exceeds the gate threshold (1.5V), see External Trigger Input section.

With the source set to MAN/REMOTE, the generator waveform is 'toggled' on and off with alternate presses of the MAN/SYNC key or by the appropriate commands via the RS232 or GPIB interfaces.

With the source set to TGEN, the generator waveform is gated on as explained in the Internal Trigger Generator section; the trigger generator is set exactly as described in the Trigger Source section.

## Amplitude Modulation

Two modes of operation are available from the AM menu:

- Amplitude Modulation using the Internal Trigger Generator as the modulation source in which the modulation depth is expressed as a percentage and constant modulation depth is maintained as the main generator (carrier) amplitude is varied.
- VCA (Voltage Controlled Amplitude) mode, in which the main generator amplitude is directly proportional to the external modulating signal voltage applied to the rear panel VCA IN socket. Suppressed carrier modulation (SCM) is achievable in this mode.

AM mode is turned on and off with alternate presses of the AM key; the lamp beside the key lights when AM mode is on. The AM parameters are all set from the AM edit menu which is selected by pressing the blue EDIT key followed by the AM key. When AM edit is selected the lamp beside the AM key flashes to show edit mode regardless of whether AM mode is currently selected to be on or off.

```
SOURCE=EXT VCA
TGEN=1.00ms 1.000kHz
INT MOD DEPTH=030%
INT MOD=SQUARE
```

## Amplitude Modulation (internal)

With the edit cursor in the SOURCE field of the AM edit menu the DIGIT keys or rotary control can be used to toggle the source between EXT VCA and TGEN (Trigger Generator) i.e. between external VCA mode and internal AM mode.

## Modulation Frequency

Select TGEN in the SOURCE field and move the cursor to the TGEN field to set the period of the Internal Trigger Generator, the modulation source for internal AM. The internal trigger generator produces a squarewave with a period that can be set from 0.02ms (50kHz) to 200s (0.005Hz). Period entries that cannot be exactly set are accepted and rounded up to the nearest available value, e.g. 0.109ms is rounded to 0.12ms. The generator output is available as a TTL level signal at the rear panel TRIG/SWEEP OUT socket.

Beside the generator period value the equivalent frequency is shown; this is for information only and is not an editable field. Because the internal trigger generator can be used by the trigger, gate, FSK and AM functions, and can be set from their respective menus, an information field is displayed in brackets beside TGEN when this is selected as the source. This field will show [FREE] when TGEN is not used elsewhere, or any of the letters [G, F, A, T] to indicate the generator is currently set as the source on the GATE, FSK, AM, or TRIG menus respectively, in addition to the menu currently displayed.

## Modulation Depth

Move the edit cursor to the INT MOD DEPTH field to set the modulation depth between 1 % and 100% in 1 % increments. The maximum output (20Vpp open circuit) cannot be exceeded and clipping will occur if modulation attempts to drive the output beyond this limit. The maximum generator output setting at which correct operation is maintained reduces from 20Vpp to 10Vpp (open circuit) as the modulation is increased from 0% to 100%.

## Modulation Waveform

The default modulation waveform is squarewave because this permits the full frequency range of the internal trigger generator to be used. Alternatively, a fixed 1kHz sinewave can be selected by moving the edit cursor to the INT MOD field in the last line of the display; the DIGIT keys or rotary control can be used to toggle the setting between SQUARE (at the frequency set on the internal trigger generator) and SINE. Note that selecting SINE forces the TGEN field to display 1.00ms 1.000kHz but the user setting is not lost and if INT MOD= SQUARE is reselected the TGEN setting returns to its original value.

## VCA (External)

With the cursor in the SOURCE field of the AM edit menu, set the source to EXT VCA. Connect the modulating signal to the rear panel VCA IN socket (nominal 6k $\Omega$  input impedance); a positive voltage increases the generator output and a negative voltage decreases the output. Note that as with internal AM, clipping will occur if the combination of generator setting and VCA signal attempts to drive the output above 20Vpp (open circuit).

External AM is achieved by setting the generator to the required output level and applying the modulation signal (which can be AC coupled if required) at the appropriate level to obtain the modulation depth required. If the generator output level is changed the amplitude of the modulating signal will have to be changed to maintain the same modulation depth. As with internal AM, the maximum output setting of the generator at which clipping is avoided is reduced from 20Vpp to 10Vpp (open circuit) as modulation is increased from 0% to 100%. Modulation frequency range is DC to 100kHz.

The generator's amplitude control circuit has four quadrant operation, allowing the generator output to be inverted if the external VCA voltage is taken sufficiently negative. Suppressed carrier modulation (SCM) can be achieved by applying a modulating signal with a negative offset between 0V and -3V (depending on output level setting) sufficient to reduce the carrier output to zero.

It is also possible to modulate a DC level from the generator with a signal applied to VCA IN, as follows. Set the generator to 0Hz sine wave on the Main menu and +90° phase on the Trigger menu. Select EXT TRIG (the default) and turn Trigger mode on with the TRIG key but do not apply a trigger signal. The MAIN OUT is now set at the peak positive voltage defined by the amplitude setting on the Main menu; setting -90° phase on the Trigger menu will give the peak negative voltage. Select EXT VCA on the AM edit menu and turn AM on; the DC level will now be modulated by the signal applied to the VCA IN socket.