FREQUENCY DEVICES™

440 SERIES TUNEABLE QUADRATURE SINEWAVE OSCILLATORS

FREQUENCY DEVICES INC

T-50-09

FEATURES

- Quadrature Sinewave Outputs
- Low Distortion
  SIN: 0.2% THD
  COS: 0.08% THD
- Tuning Range: 1000:1 (All Models)
- Frequencies from 0.05Hz to 20kHz

APPLICATIONS

- Distortion Testing
- Resolver Excitation
- Sinewave Signal Source
- Production Test

DESCRIPTION

Frequency Devices' 440 Series Resistive Tuneable Sinewave Oscillators deliver two simultaneous quadrature outputs which are 90° out of phase to each other. Featuring high waveform purity, the Total Harmonic Distortion (THD) is less than 0.08% for the COS output and less than 0.2% for the SIN output.

All 440 Series models are user-adjustable over a 1000:1 frequency range. Specific frequency selection is achieved by two nominally equal, standard ± 1% tolerance resistors, which both tune the frequency and maintain the amplitude ratio between the quadrature outputs.

The APPLICATIONS section of this specification presents detailed procedures for selecting, programming and range-switching 440 Series oscillators. Also presented is a method for continuous tuning using a dual-ganged potentiometer, F.D.I. Part Number AB98093 or AB99072.

Frequency Devices furnishes computer-selected tuning resistor-pairs as a convenience option. Simply specify the oscillator model, the desired frequency (or frequencies) or, if you wish, the corresponding calculated resistor values.

MODEL NUMBER	TUNING RANGE (f_O)		AVAILABLE INSTALLATION SOCKET	PACKAGE
	FROM	TO		
440	0.05Hz	50Hz	S1012	C-3
442	0.5Hz	500Hz	S1012	C-2
444	20Hz	20kHz	S1012	C-2

TABLE I: Available Models

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SPECIFICATIONS

(Typical @ 25°C and V_S = ±15V unless noted)

OSCILLATION FREQUENCY (f_O)	
Tolerance[1]	±3%
Externally Adjustable Range	1000:1
Drift vs. Temperature[2]	0.01%/°C
Drift vs. Supply Voltage or Output Amplitude	0.01%/%
OUTPUT[3]	
SIGNAL	
Preset Amplitude	10Vp-p ±5%
Adjustable	2.5–20Vp-p
Stability vs. Temperature	0.02dB/°C
Stability vs. Supply Voltage	0.02dB/%
Rated Current @ 20Vp-p	5mA
Resistance	1Ω
AMPLITUDE RATIO	
Initial	0.3dB
Drift	0.0008dB/°C
Drift vs. Supply Voltage or Output Amplitude	0.01%/%
QUADRATURE PHASE ERROR	+0.0°, −0.1°
DISTORTION	
Harmonic SIN Output	0.2%
COS Output	0.08%
Non-Harmonic	200μV
POWER SUPPLY (±V_S) (DC)	
Operating Voltage	±12V to ±18V
Quiescent Current	20mA
TEMPERATURE	
Operating	0°C to +70°C
Storage	−25°C to +85°C

NOTES:

1) Applicable for ±1% tolerance tuning resistor-pair having nominal value closest to that predicted by Equation 1.
2) Applicable when using 25ppm/°C tuning resistors; 100ppm/°C resistors will degrade drift specification by a factor of two.
3) Short circuit protected to ground. DO NOT CONNECT EITHER OUTPUT to $+V_S$ or $-V_S$.
4) Assumes oscillator is tuned for f_{max} by connecting short circuit in place of each tuning resistor. Worst case condition assumes a 2% tuning-resistor mismatch for a 0.3dB specification.

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TUNING FORMATS

A choice of three fundamental tuning formats enables the user to select the 440 Series output frequency in a manner best suited to the application. The techniques associated with each format will be discussed relative to advantages, trade-offs and proper implementation.

The formats to be discussed are the following:

TECHNIQUE 1 - Selection of a single specific frequency.

TECHNIQUE 2 - Programming and range switching.

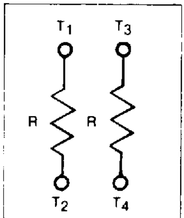
TECHNIQUE 3 - Continuous tuning over a range of frequencies.

TECHNIQUE 1 - Single Frequency Selection:
Equation (1) defines the nominal value of each tuning resistor R in Figure 1:

$$R(K\Omega) \simeq 2\left[\frac{f_{max}}{f_o} - 1\right] \quad \text{......... Eq (1)}$$

with f_o the desired oscillation frequency and f_{max} the maximum permissable oscillation frequency of the model being tuned.

Figure 1



MODEL NUMBER	f_{max} (Hz)
440	50
442	500
444	20k

The ratio of the amplitudes of the SIN and COS outputs varies with the ratio of the two tuning resistors. For this reason, metal film resistors having a ±1% tolerance and a 25 or 50ppm/°C temperature coefficient are recommended for use as tuning components. If two nominally equal, standard value, ±1% tolerance tuning resistors of the nominal value closest to that predicted by Equation 1 are used, frequency selection will be accurate to within ±3%. For even greater accuracy, trim the R's to a more closely approach to calculated value. For user convenience, Table 2 lists the 1% Resistor Standard Decade Values.

1.00	1.21	1.47	1.78	2.15	2.61	3.16	3.83	4.64	5.62	6.81	8.25
1.02	1.24	1.50	1.82	2.21	2.67	3.24	3.92	4.75	5.76	6.98	8.45
1.05	1.27	1.54	1.87	2.26	2.74	3.32	4.02	4.87	5.90	7.15	8.66
1.07	1.30	1.58	1.91	2.32	2.80	3.40	4.12	4.99	6.04	7.32	8.87
1.10	1.33	1.62	1.96	2.37	2.87	3.48	4.22	5.11	6.19	7.50	9.09
1.13	1.37	1.65	2.00	2.43	2.94	3.57	4.32	5.23	6.34	7.68	9.31
1.15	1.40	1.69	2.05	2.49	3.01	3.65	4.42	5.36	6.49	7.87	9.53
1.18	1.43	1.74	2.10	2.55	3.09	3.74	4.53	5.49	6.65	8.06	9.76

TABLE 2: 1% Resistor Standard Decade Values

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TECHNIQUE 2 · Programming and Range Switching:
All 440 Series Oscillators include frequency programming terminals by which external resistors, capacitors and switching elements can determine the oscillation frequency f_o.

Capacitive Range Switching: Connected as shown in Figure 2, matched pairs of external capacitors can range-switch all 440 Series Oscillators. This technique can maintain tracking between quadrature outputs to within specified limits, while tuning the oscillator over as many as five or more decades of frequency.

The value of the external matched capacitors, $C_{ext.}$, is express by

$$C_{ext} = C_{int}\left[\frac{f_{max}}{f_o}-1.\right] \quad \text{Eq (2)}$$

where C_{int} and f_{max} are nominal characteristics of each 440 Series model. Their values are listed in Table 3. The oscillation frequency is f_o and C_{ext} is the theoretical value of the external capacitor required. Equation3 refers to a 2kΩ internal resistance and requires that $f_o \leqslant f_{max}$

Transposing Equation 2 gives the frequency of oscillation as:

$$f_o = f_{max}\frac{C_{int.}}{C_{int.} + C_{ext.}} \quad \text{Eq (3)}$$

with the same parameter definitions.

Polycarbonate capacitors are recommended for best waveform purity; their low dissipation factor is essential to maintaining low distortion. For critical applications, mechanical switching is recommended over semiconductor switching.

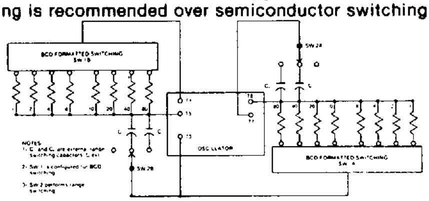

FIGURE 2 Connection of tuning and range switching components

MODEL NUMBER	f_{max} (Hz)	$C_{int.}$ (µF)
440	50	1.59
442	500	0.159
444	20k	0.00398

$f_{max} = \frac{0.159}{(2000) \times C_{int}}$: C_{int} in µF

TABLE 3: Nominal Characteristics for 440 Series Oscillators

Programming Resistor Selection: Matched pairs of external resistors connected as in Figure 2 can simultaneously tune both quadrature outputs over the 1000:1 specified frequency range. The amplitude ratio between the quadrature (SIN and COS) outputs, as well as accuracy and linearity of tuning, directly depend upon the accuracy and match of each tuning resistor pair. This flexible approach is equally suited for selecting a single frequency, a group of precisely-set incremental frequencies or widely separated frequencies, as in range-switching.

Figure 2 shows an example of binary coded decimal (BCD) programming, with the resistor of each decade weighted in an 8-4-2-1 format. The programming resistor values are given by:

$$R(K\Omega) = 2\,\frac{f_{max}}{f_o} \quad \text{Eq (4)}$$

with f_{max} and f_o defined as before.

To obtain incremental oscillation frequencies of 1kHz, 2kHz, 4kHz and 8kHz requires F.D.I.'s Model 444. For this BCD example, first compute the resistor value corresponding to the lowest frequency (1kHz) and the least significant bit (L.S.B.). Equation 4 gives

$R(1)\,(k\Omega) = 2\,\frac{(20kHz)}{(1kHz)}$, or $R(1) = 40k\Omega$, nominal. The next highest frequency requires half the resistance, so that $R(2) = 20k\Omega$, nominal. Table 2 lists the calculated and recommended resistor values for this example. THE USER SHOULD SELECT THE NEAREST STANDARD 1% RESISTOR VALUE FOR TUNING EACH DESIRED FREQUENCY.

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Programming Resistor Selection, continued

BCD Bit (Weighting)	1	2	4	8
f_o (kHz)	1.0	2.0	4.0	8.0
Calculated Resistance (Eq 3)	40k Ω	20k Ω	10k Ω	5k Ω
Recommended 1% Resistor Value	40.2k Ω	20k Ω	10k Ω	499k Ω

TABLE 4: Values and Performance of BCD Programming Example

Switching Element Selection: Electronically-signalled frequency switching is performed by either the field effect transistor (FET) with its faster switching rate and higher ON resistance, or the reed relay with its comparatively slower switching rate and lower ON resistance. Because the switching element is in series with the internal 2k Ω programming impedance, the ON resistance of the switch contributes increasing amounts of error with the selection of higher frequencies. Along with this, any mismatch between switch pairs having significantly large ON resistance can degrade quadrature output tracking.

Care must be taken that the large signal characteristics of a FET analog switch can accommodate the full scale voltage and current demands of the signal being switched. For example, at $f_o = f_{max}$, they could be required to accommodate a full scale 10V peak signal, while driving the 2k Ω programming impedance.

For manually-switched applications rotary or thumbwheel switches plus a bank (or banks) of toggle switches are suitable for the task.

TECHNIQUE 3 - Continuous Tuning:
Frequency Devices offers dual-ganged potentiometer for applications requiring front-panel knob control of the oscillator f_o. While providing continuous frequency tuning, these potentiometers introduce mismatch which degrades the amplitude ratio tracking of the SIN and COS outputs. The mechanical linkage between ganged resistive elements can create a mismatch of up to ± 5%; this would degrade the output amplitude ratio by approximately 2dB.

Many applications are satisfied by a single phase, high purity sine or cosine input. The optional potentiometers are recommended for these applications as well. Here, the potentiometers will maintain acceptable tracking between quadrature output for minimal distortion, while providing high resolution tuning by virtue of logarithmically-tapered resistance elements. **The user must implement the connections in Figure 3; the potentiometers are furnished unwired.**

CAUTION: PINS T5 and T6 ARE EXTREMELY SENSITIVE POINTS. TO MAINTAIN SPECIFIED HIGH PERFORMANCE, THE LEAD LENGTH OF ANY TUNING COMPONENT SHOWN IN FIGURE 2 WHICH CONNECTS TO T5 OR T6 MUST BE KEPT TO AN ABSOLUTE MINIMUM.

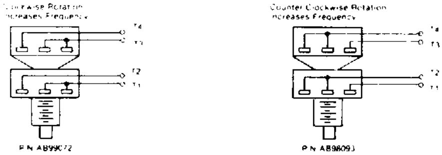

FIGURE 3 Connections to Optional Tuning Potentiometers
Potentiometers are furnished unwired

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An external control voltage (V_C) can simultaneously adjust both quadrature output levels of all 440 Series Oscillators. Connected as in Figure 4, V_C is capable of increasing or decreasing the outputs, while maintaining the specified ratio between their amplitudes.

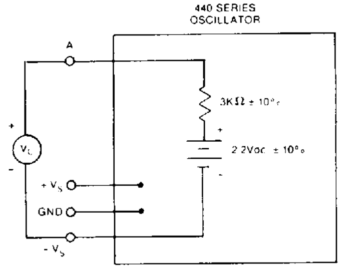

FIGURE 4: Internal and External Control Circuitry

It is important to refer (connect) V_C to the negative power supply voltage ($-V_S$). If referenced to the positive supply voltage ($+V_S$), the control voltage would couple any variation of that supply, producing a proportional variation of the oscillator quadrature outputs. If the application requires V_C to be referenced to the positive power supply voltage ($+V_S$), the polarity of V_C must be opposite to that shown in Figure 4.

Figure 4 illustrates the equivalent circuit that the oscillator module presents to the external control voltage source (V_C). The simplified circuit is useful for establishing that series-opposing polarities exist between the internal and external sources.

Figure 5 illustrates the level of peak-to-peak quadrature output voltage as a function of external input control voltage, with power supply voltages of ± 15V dc.

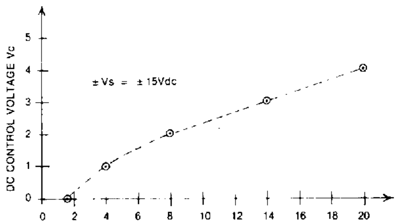

FIGURE 5: Control Voltage Influence on Output levels

OPERATION FROM A SINGLE-ENDED POWER SUPPLY

The 440 Series oscillators are specified for operation from dual power supplies between ± 12V to ± 18V. Should it be necessary to operate from a single ended supply the circuit of Figure 6 would be used for interface between the supply and the oscillator. Since the oscillator will operate from ± 12V to ± 18V, the single-ended supply must be between +24 and +36 volts. Observing specified levels, the output would be a ± 10V swing about $+V_S/2$.

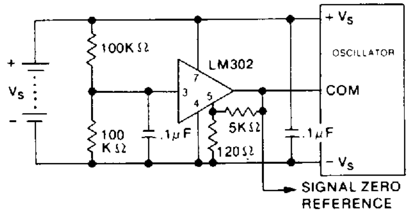

Figure 6: Single-supply operation

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INTRODUCTION

Connected to analog multipliers as Figures 7 and 8, any 440 Series model can function as a high performance voltage controlled oscillator (VCO). The discussions below describe two methods by which an external DC control voltage tunes the frequency of oscillation.

METHOD A

This implementation of a VCO provides the maximum attainable frequency adjustment range and appears in Figure 7. The operating frequency is:

$$f_o = f_{omax}\left(\frac{2000}{2000 + R}\right)\left(\frac{V_c}{10}\right) \text{ . . Eq 5}$$

The value for both resistors labelled R is given by:

$$R(\Omega) = 200\left(V_c\frac{f_{omax}}{f_o} - 10\right) \text{ . . . . Eq 6}$$

where:

f_o is the desired oscillation frequency.

f_{omax} is 50Hz for Model 440
500Hz for Model 442
20kHz for Model 444

V_c is the DC control voltage in volts $0 < V_c \leq +10$Vdc.

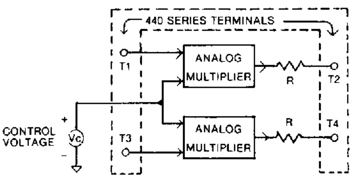

FIGURE 7: A VCO Approach Configured for Maximum Frequency Range

Pins T1 through T4 are external device terminations which connect to internal oscillator control points. Please refer to the dimension drawing further on for the location of these pins.

METHOD B

This VCO circuit of Figure 8 trades off tuning range to obtain reduced distortion, DC offset and noise.

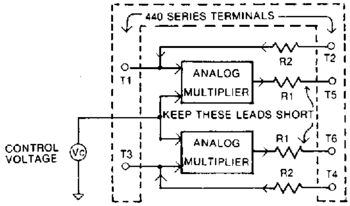

FIGURE 8: This VCO Approach Minimizes Noise, Distortion and DC Offset, but the Tuning Range Is Narrower.

The operating equations are as follows:

$$f_o = f_{o\,nom}(1 \pm \Delta) \text{ . . . . Eq 7}$$

$$f_{o\,nom} = f_{omax}\left(\frac{2000}{R2 + 2000}\right) \text{ . . . . Eq 8}$$

$$\Delta = f_{o\,nom}\left(\frac{2000 + R2}{R1}\right)\left(\frac{V_c}{10}\right) \text{ . Eq 9}$$

$$R2(\Omega) = 2000\left(\frac{f_{omax}}{f_{o\,nom}} - 1\right) \text{ . . . . Eq 10}$$

$$R1(\Omega) = f_{o\,nom}\left(\frac{2000 + R2}{\Delta}\right)\left(\frac{V_c}{10}\right);$$

$$R1 \geq 2k\Omega,\ R2 \geq 0\Omega \text{ . . . . Eq 11}$$

where

f_{omax} is 50Hz for Model 440
500Hz for Model 442
20kHz for Model 444

V_c is the DC control voltage:
$-10V \leq V_c \leq +10V$;
for negative V_c, f_o will sweep below f_o nom.
For positive V_c, f_o will sweep above f_o nom.

NOTE: The drive capability of the multiplier dictates the minimum permissable value of R1.

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440 SERIES APPLICATION HINTS FAST START TECHNIQUES

FREQUENCY DEVICES INC

INTRODUCTION

External circuits can minimize 440 Series turn-on transient which results from internal capacitive charging requirements. This discussion describes two recommended speed-up techniques, one manual and one automatic. Both techniques use readily available components. For location of device pins, refer to the dimension drawings presented further on.

METHOD A - Manual Fast-Start:
The triple-pole double throw switch of Figure 9 provides the following shortened initial charge times:

Model 440:
$T(Sec) = (S/B\ 10^{-4})(V_{cos\ p\text{-}p})$

Model 442:
$T(Sec) = (S/B\ 10^{-6})(V_{cos\ p\text{-}p})$

Model 444:
$T(Sec) = (S/B\ 10^{-7})(V_{cos\ p\text{-}p})$

The components and key operating levels are defined as follows:

$R_Z = 1.5k\Omega$, ¼ watt

$I_Z = 10mA$ min

$$V_Z = \left(\frac{V_{cos\ p\text{-}p}}{2}\right)$$

SW.1: Can be implemented by a mechanical switch or by appropriately configured reed relays. Triple-pole GANGED operation is RECOMMENDED.

To apply this technique, close the switch (SW.1) for the value of T(Sec) corresponding the 440 Series model being used. Then open SW.1. The oscillator will start instantly provided $V_Z = (V_{cos\ p\text{-}p})/2$. Any difference will result in the oscillator output setting to the actual value of V_Z over a somewhat longer time.

METHOD B - **Automatic Fast Start:**
The circuit shown in Figure 10 trades speed for automation, but eliminates the need for relatively high priced switching elements. In addition, this method provides automatic start-up with a significantly shorter turn-on delay compared to a basic 440 Series Oscillator.

The operating equations for the circuit of Figure 10 are as follows:

$$C = \frac{V_{peak}}{+V_S}(C2)\ldots \text{where}$$

V_{peak} = The peak value of the output

$+V_S$ = The positive power supply

R1 = 2kΩ, ¼ watt metal film

CR1 = General purpose, silicon signal diode

C2 is 3.18µF for Model 440
0.159µF for Model 442
0.00399µF for Model 444

Use of a power supply having low output ripple and noise is strongly recommended. This is because noise on the $+V_S$ bus will couple through the start-up circuit to the oscillator output. Frequency Devices' Model 100-15B60-01, dual 15V power supply would be an excellent choice for this application.

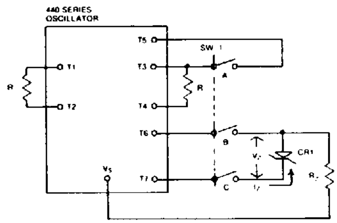

Figure 9: A Manual Fast Start Circuit

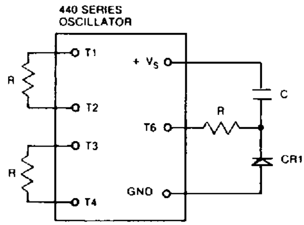

FIGURE 10: Automatic Fast Start Circuit

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440 SERIES CASE & SOCKET DIMENSIONS

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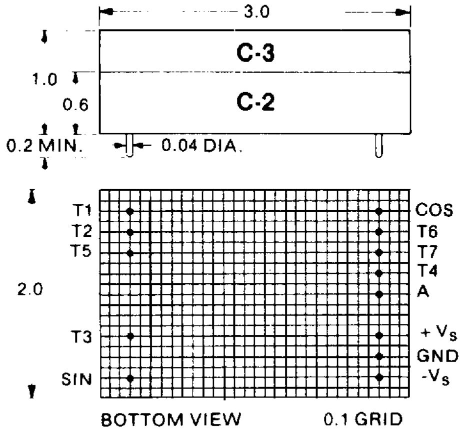
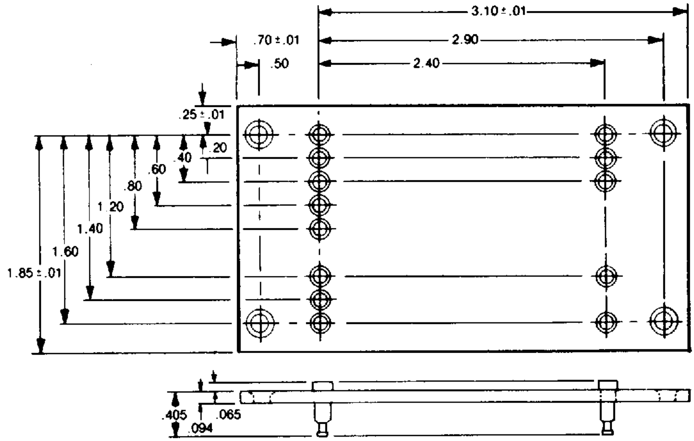


TERMINAL KEY

COS	Cosine Output
SIN	Sine Output
A	Amplitude Control Terminal
$+V_s$	Positive DC Supply
GND	Signal & Supply Common
$-V_s$	Negative DC Supply
T1	The seven terminals T1 toT7 are used in the various tuning and range switching schemes. If the use of any particular terminal is not called for it should be left in open circuit configuration. Do not short to power supply.
T2	
T3	
T4	
T5	
T6	
T7	

MATING SOCKET S1012 DIMENSIONS



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OSCILLATORS

To order the Model 440, 442, or 444 you need only specify the complete part number and the quantity.

For example: 10 each Model 442

TUNING RESISTORS

To order frequency selection resistors specify either the ± 1% tolerance resistor value closest to your calculated value or specify the frequency and model number and Frequency Devices will provide the correct resistor value. If F.D.I. is to do the resistor calculation also specify whether the tuning scheme employing Equation (1) or Equation (4) is desired. For example:

QUANTITY	PART NUMBER DESCRIPTION	EQUATION
1	Set of 2 Tuning Resistors for Model 442, f = 400Hz	Eq (1)
1	Set of 2 Tuning Resistors for Model 444, f = 5kHz	Eq (4)

ACCESSORIES

Call out the item and the quantity. For example:

QUANTITY	PART NUMBER	DESCRIPTION
10 ea	AB98093	Dual Ganged Potentiometer
100 ea	S1012	Installation Socket
30 ea	79PR1K	Potentiometer
10 ea	665	Amplitude Control Module

TELEPHONE, TWX, TELEX OR MAIL THE ORDER.

Please address your confirming order as follows:

Frequency Devices, Inc.
25 Locust Street
Haverhill, Massachusetts 01830
Attention: Order Desk

Acknowledgement of the order will be forwarded.

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