Multi-channel signals with programmable inter-channel phase

This solution requires a C-size VXI cage, a control card, an E1420A counter and, if more than two E1440As are used, an E1366A switching unit.

Features and benefits

- Slave E1440A frequencies can be a multiple of master frequency.
- Channels can be independently modulated (AM or PM).
- 11-digit frequency resolution.
- Phase accuracy +/-2 degree at 20 MHz (even better at lower frequencies due to counter's 200 ps time-interval resolution).
- Output waveforms need not be the same, and are selectable from:
  - sine (up to 21 MHz), square or triangle (up to 11 MHz), and ramp (up to 11 kHz). Minimum frequency is 1 uHz.
- 5 ppm stability, if E1440As are daisy-chained. Can be improved by using the counter reference.
- Independent amplitude 1 mVpp to 10 Vpp into 50 ohm.
  Option 001 provides 4 mVpp to 40 Vpp into 500 ohm.

Application example: Navigation Systems

Test of vehicle receivers used in Decca-type location systems requires a number of synthesizers to simulate the signals from a number of fixed transmitters. The frequencies, which are multiples of the master transmitter frequency, must not only be phase-locked, but also of programmable phase so that receiver performance can be verified for any vehicle position.

Setting up for the first time

After inserting the modules in the VXI-cage, the front panel connections shown in the following diagram must be made. Additionally, the counter's 10 MHz reference can be "daisy-chained" to all E1440As; this however is not essential, the VXI-internal CLK10 line can be used instead.

a) Two channels

Master E1440A (left)

```
  Sync Out  E1420A Counter

Slave E1440A

  Sync Out

  Input 1

  Input 2
```

b) Three to five channels

Master E1440A (furthest left)

```
  Sync Out  E1366A Switch  E1420A Counter

  00

  01
```

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Try to keep the Sync Out path lengths as equal as possible. The same applies to the main outputs. Perform a phase measurement at the device and note any offset needed. With propagation times equalized, the phase accuracy lies in the range +/-1 to +/-7 degree depending on waveform and amplitude mix, and frequency.

From here on, correct phase relationship is simply a matter of setting each slave to the required phase. Subsequently, whenever frequency, waveform or amplitude are changed, a phase-cal should be performed. If more than one counter is detected, the one with the lowest slot number will be taken.

Also, the current settings of the counter and switch are stored. This is to allow the counter to be used for other measurements. After the phase calibration, the previous counter settings are automatically recalled.

The calibration is done by the subprogram Sc_calibrate, which first measures the time delay between the positive slopes of the sync signal from the master device (which is used as a reference) and the sync signals from the slaves. It then calculates the phase error between master and slave and adjusts each slave so that all channels are in phase with the master.

After calibration, the program sets the different E1440A's to the desired phase values. Then, as mentioned above, counter and switch are returned to their previous settings.

Automaton
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UNSUPPORTED programs are attached:
1. PHASECAL: provides a user interface and phase-calibrates automatically.
2. ERRORHANDLING: a utility for use in any application where self-test is to be implemented.

The programs are in HP Basic and stored as ASCII files (use the HP Basic command GET to load the file).

PHASECAL implements phase calibration for up to five HP E1440As. If a daisy-chained reference signal is used instead of VXI line CLK10, change line 109 from:

```
109  OUTPUT Hpib E1440(I,2);";:SOURCE:ROSC:SOURCE CLK10"
```

To:

```
109  OUTPUT Hpib E1440(I,2);";:SOURCE:ROSC:AUTO ON"
```

Initially, the routine detects the cards in the VXI-cage (SUB Sc_getdev) and assigns the E1440A with the lowest slot number as master, the one with the next higher slot number will be slave 1, and so-on. If more than one E1420A counter is detected, the one with the lowest slot number will be taken.

Also, the current settings of the counter and switch are stored.
This is to allow the counter to be used for other measurements.

The calibration is done by the subprogram Sc_calibrate, which first measures the time delay between the positive slopes of the sync signal from the master device (which is used as reference) and the sync signals from the slaves. It then calculates the phase error between master and slave and adjusts each slave so that all channels are in phase with the master.

After calibration, the program sets the different E1440's to the desired phase values, and returns the counter and switch to their previous settings.

1     ! PHASE CALIBRATION UTILITY (IN RMB) FOR A MASTER E1440A
2     ! WITH UP TO FOUR SLAVE E1440As.
3     !
4     ! E1420A COUNTER MUST BE INSTALLED IN THE SAME MAINFRAME.
5     !
6     ! IF THERE IS MORE THAN ONE SLAVE, A PROGRAMMABLE CO-AX
7     ! SWITCH WILL ALSO BE NEEDED. THIS PROGRAM USES THE
8     ! E1366A SWITCH
9     !
10    !
11    !
12 REAL Counter      ! HPIB-address of E1420 e.g. 71605
13 REAL Switch       ! HPIB-address of Switchbox
14 REAL Master       ! HPIB-address of master E1440
15 REAL Frequency    ! Frequency of master E1440
16 REAL Master_phase ! Phase of master E1440 after calibration
17 REAL Slave(1:4)   ! HPIB-addresses of slave E1440's, 0 for
18     unused slaves
19 INTEGER Slave_multi(1:4)
20 REAL Slave_phase(1:4)  ! Slave phase after cal
21 REAL Error        ! Return value: 0=cal ok, 1=timeout
22 INTEGER Pm_cal    ! 0: CALIBRATION WILL BE DONE FOR PM BY
23     ! SWITCHING OFF/ON PM INPUTS
24     ! THIS MAY CAUSE FOR SQUARE WAVES A PHASE
25     ! SHIFT OF 180 DEGREES
26 !<>0: FOR SQUARE WAVES WITH PM, THE PROGRAM WILL
27     ! CALIBRATE WITH PM SWITCHED ON AND ASK
28     ! TO DISCONNECT/CONNECT THE CABLES TO THE
29     ! PM INPUTS. THIS PROTECTS FROM THE PHASE
30     ! SHIFT, BUT NEEDS MANUAL MODIFICATIONS OF
31     ! THE TEST CABLE CONNECTIONS
32 !
33 Frequency=1500
34 Slave_multi(1)=1
35 !
36 REAL Hpib ! incl sec addr. Used only for Sc_getdev subpgm
37 Hpib=71600  ! HAS TO BE CHANGED TO VALID ADDRESS
38 CALL Sc_getdev(Hpib,Counter,Switch,Master,Slave(*))
39     ! assign dev addresses
40 !CALL
41 !_c_calibrate(Counter,Switch,Master,Frequency,
42     Master_phase,Slave(*),
43     Slave_multi(*),Slave_phase(*),Error,Pm_cal)
44 END
45 !
46 !=================================================================
47 SUB Sc_getdev(Hpib,Counter,Switch,Master,Slave(*))
48 ! CHECK DEV ADDRESSES
49 ! this subprogram is only used to show how the
50 ! -=mainframe can be detected automatically. It is
51 ! not needed for calibration
52 INTEGER I,Devnumber,Count,E1440a,E1420a,Sbox
53 !!REAL Mfg,Dummy,La(1:13),E1440(1:5,1:2),Slot,Dev,
54 !!Switchbox(1:3,1:2),E1420(1:3,1:2)
55 DIM Dev$(20),Dummy$(200),Dlad$(50)
Counter=0
51 IF NOT Hpib THEN SUBEXIT
52 ON TIMEOUT INT(Hpib/10000),5 GOTO Timeout_error
53 Dev=Hpib
54 OUTPUT Hpib;":VXI:CONF:DNUM?"
55 ENTER Hpib;Dev
56 OUTPUT Hpib;":VXI:CONF:DLAD?"
57 FOR I=1 TO Dev
58 La(I)=VAL(Dlad$)
59 Dlad$=Dlad$[POS(Dlad$,"\"",1,LEN(Dlad$)]
60 OUTPUT Hpib;":VXI:CONF:DLIS? \"\"La(I)"
61 ENTER Hpib;Dummy,Dummy,Mfg,Dummy,Slot,Dummy$,
62 IF Mfg=4095 THEN       !  manufacturer hp ?
63 La(I)=INT(La(I)/8)
64 Dev=Hpib La(I)
65 OUTPUT Dev;"*IDN?"
66 ENTER Dev;Dummy$
67 Dummy$=Dummy$[POS(Dummy$,"\",1,LEN(Dummy$)]
68 Dummy$=Dummy$[1,POS(Dummy$,"\"",-1)]
69 SELECT Dummy$
70 CASE "E1440A"
71 E1440a=E1440a 1
72 Count=Count 1
73 IF Count<6 THEN
74 E1440(Count,1)=Slot
75 E1440(Count,2)=La(I)
76 END IF
77 CASE "E1420A"
78 E1420a=E1420a 1
79 E1420(E1420a,1)=Slot
80 E1420(E1420a,2)=La(I)
81 CASE "SWITCHBOX","E1472A"
82 Sbox=Sbox 1
83 Switchbox(Sbox,1)=Slot
84 Switchbox(Sbox,2)=La(I)
85 CASE ELSE
86 END SELECT
87 END IF
88 NEXT I
89 IF Count THEN
90 !!MAT SORT E1420(*,1)
91 !!MAT SORT Switchbox(*,1)
92 FOR I=3 TO 1 STEP -1
93 IF E1420(I,2) THEN
94 Count=Hpib E1420(I,2)
95 END IF
96 IF Switchbox(I,2) THEN
97 Switch=Hpib Switchbox(I,2)
98 END IF
99 END IF
100 NEXT I
101 IF E1420a=0 THEN PRINT "CONFIG ERROR: No E1420 cntr"
102 IF Sbox=0 AND E1440a>1 THEN
103 PRINT "CONFIG MESSAGE: No Switchbox"
104 END IF
105 IF E1440a<2 THEN PRINT "CONFIG ERROR: No E1440"
106 OFF TIMEOUT
107 SUBEXIT
SUB Sc_calibrate(Counter, Switch, Master, Frequency, Master_phase, Slave(*),
  INTEGER Slave_multi(*), REAL Slave_phase(*), Error, INTEGER Pm_cal)

REAL Master_pm, Slave_pm, Test1, Test2, J, Slave_frequency, Fault
DIM Master_wave$(15), Slave_wave$(15)

IF NOT Master OR NOT Counter THEN SUBEXIT ! no master or counter addr
IF Master<10000 OR Counter<10000 THEN SUBEXIT ! incomplete addr
ON TIMEOUT INT(Master/10000),7 GOTO No_count !timeout? -> abort

OUTPUT Master;"*:FREQ:FIX "&VAL$(Frequency)&"HZ;*:SOURCE:PM:STATE?"

ENTER Master;Master_pm
OUTPUT Master;":SOURCE:FUNCTION:SHAPE?"

ENTER Master;Master_wave$
IF Master_wave$="DC" THEN SUBEXIT ! no calibration for dc
OUTPUT Counter;"*:SAV 9" ! save counter setup
!!OUTPUT Counter;":INP1:ROUTE SEP;:SENSE1:EVENT:SLOPE
!!POS;:SENSE2:EVENT:SLOPE POS;:INPUT1:COUP DC;:INPUT2
!!!:COUP DC;:INP1:IMP 50;:INP2:IMP 50"

!!OUTPUT Counter;":SENSE1:EVENT:LEVEL:AUTO OFF;
:SENSE1:EVENT:LEVEL
!!ABS 1.5V;:SENSE2:EVENT:LEVEL:AUTO OFF;
:SENSE2:EVENT:LEVEL:ABS 1.5V"

IF (Switch MOD 10000) THEN OUTPUT Switch;"*:SAV 9;
:ROUT:CLOS (@100)"
!!save mux settings, switch mux to connect master to counter input 1
ON TIMEOUT INT(Counter/10000),7 GOTO No_cal
IF (Master_wave$<>"SQUARE") OR Master_pm<>1 OR Pm_cal=0 THEN
  OUTPUT Master;":SOUR:PM:STAT OFF"
ELSE ! select desired and necessary calibration
  Test1=0 ! output has normal phase during calibration
  PRINT "CALIBRATION MESSAGE: Please disconnect cable from PM input"
  !!!ON KBD ALL GOTO !152
  GOTO 151 ! wait for user action
  !!OFF KBD
END IF

IF Master_phase<>Test1 THEN
  FOR J=Master_phase TO Test1 STEP (Test1-Master_phase)/15
    !! omit phase shift below 25 kHz
    OUTPUT Master;":SOUR:PHAS "&VAL$(PROUND(J,-1))&" DEG"
  NEXT J
END IF

FOR I=1 TO 4
  IF Slave(I) AND ((I=1) OR (Switch MOD 100)) THEN
    !!IF (Switch MOD 10000) THEN OUTPUT Switch;":ROUT
    :clos (@11"&VAL$(I-1)&")
    !! "Slave_frequency=Frequency*Slave_multi(I)
    ! calculate new slave frequency
    OUTPUT Slave(I);":FREQ:FIX "&VAL$(Slave_frequency)&"HZ;
    :SOURCE:PM:STATE?"
  ENTER Slave(I);Slave_pm ! check slave for pm
  OUTPUT Slave(I);":SOURCE:FUNCTION:SHAPE?"
173 ENTER Slave(I);Slave_wave$    ! check slave waveform
174 IF Slave_wave$<>"DC" AND Slave_frequency<2.1E 7 THEN
175 !! !  no calibration for dc or frequencies above 21MHz
176 IF (Slave_wave$="SQUARE") OR Slave_pm<>1 OR Pm_cal=0
177 THEN
178 OUTPUT Slave(I);":SOUR:PM:STAT OFF"
179 Test2=180
180 ELSE
181 Test2=0
182 PRINT "CALIBRATION MESSAGE: Please disconnect
183 !" at slave"&VAL$(I)&" device ("&VAL$(Slave(I))&")
184 ! then press any key"
185 !!ON KBD ALL GOTO 176
186 !! GOTO 175    !  wait for user action
187 !!!OFF KBD
188 END IF
189 IF Slave_phase(I)>(180-Test2) THEN
190 FOR J=Slave_phase(I) TO 180-Test2 STEP (180-Slave_phase(I))/15
191 !!! omit phase shift below 25 kHz for phase changes
192 > 25 deg (squarewave)
193 OUTPUT Slave(I);":SOUR:PHAS"&VAL$(ROUND(J,-1))&" DEG"
194 NEXT J
195 END IF
196 ! CALL Sc_measure(Counter,Master,Slave(I),Test2,
197 Slave_frequency,Fault)
198 ! IF ABS(Fault-180)<179.5 THEN OUTPUT Slave(I);":SOUR:
199 PHAS "&VAL$ 
200 !! (Fault)&" DEG;SOURCE:PHASE:REFERENCE"
201 IF Slave_phase(I) THEN
202 FOR J=0 TO Slave_phase(I) STEP (Slave_phase(I))/15
203 ! omit phase shift below 25 kHz
204 OUTPUT Slave(I);":SOUR:PHAS "&VAL$(ROUND(J,-1))&" DEG"
205 NEXT J
206 END IF
207 OUTPUT Slave(I);":SOUR:PM:STAT "&VAL$(Slave_pm)
208 IF (Slave_wave$="SQUARE") AND Slave_pm=1 AND Pm_cal<>0
209 THEN
210 !!! PRINT "CALIBRATION MESSAGE: Please connect cable to
211 ! PM input at
212 slave"&VAL$(I)&" device ("&VAL$(Slave(I))&") then
213 ! press any key"
214 !! ON KBD ALL GOTO 197
215 GOTO 196    !  wait for user action
216 !!!OFF KBD
217 END IF
218 END IF
219 END IF
220 NEXT I
221 IF Test1<>Master_phase THEN
222 FOR J=Test1 TO Master_phase STEP (Master_phase-Test1)/15
223 ! omit phase shift below 25 kHz for changes > 25 deg (only
224 for squarewave)
225 OUTPUT Master;":SOUR:PHAS "&VAL$(ROUND(J,-1))&" DEG"
226 NEXT J
227 END IF
228 OUTPUT Master;":SOUR:PM:STAT "&VAL$(Master_pm)
229 IF (Master_wave$="SQUARE") AND Master_pm=1 AND Pm_cal<>0
230 THEN
231 !!! PRINT "CALIBRATION MESSAGE: Please connect cable to
232 ! PM input at
233 master device ("&VAL$(Master)&") then press any key"
234 !! ON KBD ALL GOTO 212
235 GOTO 211    !  wait for user action
236 !!!OFF KBD
237 END IF
238 END IF

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229  OUTPUT Counter;"*rcl 9"         ! re-store counter setup
230  IF (Switch MOD 10000) THEN OUTPUT Switch;"*rcl 9"
      ! re-store mux setup
231  OFF TIMEOUT
232  Error=0     ! no error occurred
233  SUBEXIT
234  No_cal:!!
235  ON TIMEOUT INT(Counter/10000),7 GOTO No_count
236  ! if device timeout then abort
237  OUTPUT Counter;"*rcl 9"         ! re-store counter setup
238  IF (Switch MOD 10000) THEN OUTPUT Switch;"*rcl 9"
      ! re-store mux setup
239  No_count:      !
240  OFF TIMEOUT     ! calibration not successful, timeout
241  SUBEND
242  !================================================
243  SUB Sc_measure(Counter,Master,Slave,Test2,Frequency,Fault)
244  REAL Resolution,Measure(1:3),J,Tout
245  IF Frequency>2000 THEN
246  ! select measurement resolution of counter depending on
247  REAL Resolution=1.E-10
248  ELSE
249  Resolution=1.E-9
250  END IF
251  REAL Tout=3/Frequency 5
252  Sc_getdelay(Frequency,Resolution,360,Counter,Tout,Measure(1))
253  Sc_getdelay(Frequency,Resolution,360,Counter,Tout,Measure(2))
254  !IF (ABS(Measure(2)-Measure(1))>1.5) AND ((ABS
255  OR (ABS(Measure(2)-180)<179)) THEN
256  ! both values in tolerance?
257  ON TIMEOUT INT(Counter/10000),5 GOTO End
258  FOR J=180-Test2 TO Test2 STEP (Test2/5-18)
259  ! omit phase shift below 25 KHz for phase changes >
260  OUTPUT Slave;":SOUR:PHAS "&VAL$(PROUND(J,-1))&" DEG"
261  NEXT J
262  WAIT .3
263  Sc_getdelay(Frequency,Resolution,540,Counter,Tout,Measure(3))
264  !IF (ABS(Measure(2)-Measure(3))>2) AND ((ABS
265  OR (ABS(Measure(3)-180)<178.5) OR
266  ! (ABS(Measure(3)-180)<178.5)) THEN
267  ! compare second with third measurement
268  Measure(3)=Measure(1)
269  Measure(1)=Measure(3)
270  Sc_getdelay(Frequency,Resolution,540,Counter,Tout,Measure(3))
271  !IF (ABS(Measure(1)-Measure(3))>3) AND ((ABS
272  OR (ABS(Measure(1)-180)<178) OR
273  ! (ABS(Measure(3)-180)<178)) THEN 246
274  ! last two measurements in tolerance?
275  Measure(2)=Measure(3)
276  ELSE
277  Measure(1)=Measure(3)
278  END IF
279  FOR J=Test2 TO 180-Test2 STEP (18-Test2/5)
280  ! omit phase shift
281  OUTPUT Slave;":SOUR:PHAS "&VAL$(PROUND(J,-1))&" DEG"
282  NEXT J
283  END IF
284  IF Measure(1)>355 AND Measure(2)<5 THEN Measure(1)=
285  Measure(1)-360
286  IF Measure(2)>355 AND Measure(1)<5 THEN Measure(2)=
287  Measure(2)-360

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282  Fault=PROUND((Measure(1) Measure(2))/2,-1)
283      ! that's the phase error
284  BEEP 200,.05        ! MEASUREMENT DONE
285 End:OFF TIMEOUT
286 SUBEND
287 SUB Sc_getdelay(Frequency,Resolution,Degree,Counter,Tout,
288       Measure)
289  OFF TIMEOUT
290  IF Tout<32 THEN
291    ! if calibration needs longer than 32.767 seconds, the
292    ! timeout command can't be used to avoid a hang-up
293    ON TIMEOUT INT(Counter/10000),Tout GOTO T_out
294 ELSE
295    ! ON TIME Tout GOTO T_out
296 END IF
297 OUTPUT Counter;":MEASURE1:TINTERVAL? 1,"&VAL$(Resolution)
298 ENTER Counter;Measure
299 Measure=(PROUND(Measure*Frequency*360,-1) Degree) MOD 360
300 T_out:OFF TIMEOUT
301 SUBEND

Part 4.

10    !E1440A Self-cal error-handling routine.
20    !Prints "self-cal OK" or, if there is a fault, the
21    self-cal results.
30    !A timeout recovers system control if the E1440A fails
31    to respond.
40    CLEAR SCREEN
50    ASSIGN @Fg TO 71611
60    ABORT 7
70    CLEAR 7
80    CLEAR @Fg
90    !
100   Cal$=" 9"
110   !
120   !
130   OUTPUT @Fg;"*RST;:STATUS:PRESET;*CLS"
140   OUTPUT @Fg;":VOLT 5V" ! This statement causes self-cal
150   ON TIMEOUT 7,3 GOTO Timeout
160   OUTPUT @Fg;":CAL?" ! Self-cal data requested
170   ENTER @Fg;Cal$ ! Self-cal data uploaded
180   IF Cal$=" 0" THEN
190       PRINT "Self-cal ok"
200 ELSE
210       PRINT "Self-cal error ";Cal$;"see Manual p 5-9"
220 END IF
230 GOTO End
240 !
250 Timeout:PRINT "Timeout, E1440A doesn't respond within normal self-cal time (3 s)"
260 !
270 End:LOCAL @Fg
280 !
290 END