Errata

Document Title: External Frequency Doubling of the 8662A Synthesized Generator (AN 283-2)

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HP References in this Application Note

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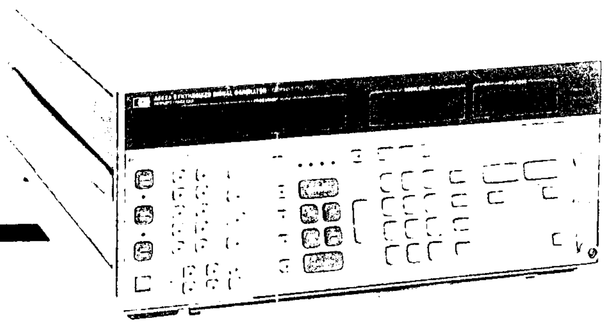

Application Note 283-2

External Frequency Doubling of the 8662A Synthesized Signal Generator

The Hewlett-Packard 8662A Synthesized Signal Generator provides exceptionally pure synthesized signals from 10 kHz to 1280 MHz. This frequency range can be extended to 2560 MHz through the use of an external frequency doubler, such as the HP 11721A (Figure 1). Although frequency doubling preserves certain 8662A characteristics, other areas of performance may be somewhat degraded and care should be taken to insure that such degradation does not affect a given application. This application note explains the properties of broadband passive external frequency doublers and the effects of the HP 11721A Frequency Doubler upon the RF output characteristics of the 8662A.

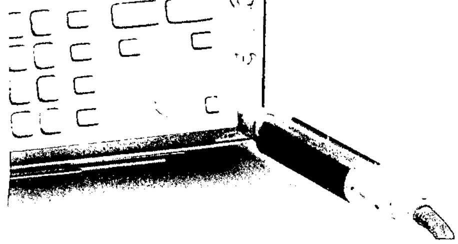

Figure 1. 8662A with 11721A Frequency Doubler attached.

Theory of Doubler Operation

Figure 2 shows a circuit diagram of a typical passive frequency doubler.

The circuit consists of a full-wave rectifier that generates even harmonics of the input frequency. Theoretically, a full-wave rectifier yields an output

$$y(t) = \frac{4A}{\pi}\left[\frac{1}{2} + \frac{1}{3}\cos 2\omega t - \frac{1}{15}\cos 4\omega t + \frac{1}{35}\cos 6\omega t \; \ldots - (-1)^n (4n^2 - 1)^{-1} \cos 2n\omega t\right] \qquad (1)$$

where ω = input frequency in radians per second and A = input amplitude.

From this series it can be seen that the dominant output frequency component is the desired doubled input frequency. Note the absence of the input frequency and its odd harmonics. In actual practice these odd harmonic components are always present at the output, although at somewhat lower levels than the even harmonics. The odd harmonics result from uneven full-wave rectification of the input waveform due to unavoidable imbalances in the diode forward resistances and in the transformer construction. Some applications may require filtering to suppress these relatively high level frequency components.

Figure 3 shows a typical frequency output spectrum of the HP 11721A frequency doubler with an input frequency of 100 MHz at +13 dBm. Note the frequency axis labeling of the input frequency as f/2, the desired second harmonic of the input as f, the third harmonic as 3f/2, and so on. This is the customary method of naming doubler harmonics.

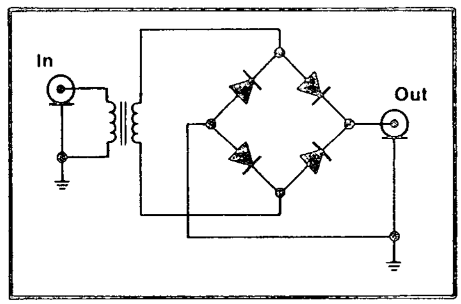

Figure 2. Typical frequency doubler circuit.

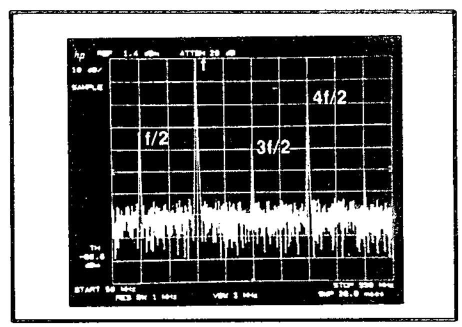

Figure 3. Output spectrum of HP 11721A as seen on HP 8566A Spectrum Analyzer.

Output Power

In many applications, the most serious problem resulting from the use of an external frequency doubler is the loss of power known as conversion loss or doubling loss. Referring to the output frequency spectrum given in (1), the desired doubled output is seen to have an amplitude equal to $4/3\pi$ times the input amplitude. Thus, there is an inherent minimum doubling loss of 20 log $(4/3\pi) \cong 7.4$ dB. In practice, typical doubling losses are greater than this due to transformer and diode losses and range from 11 to 15 dB at the specified required input level. As a result, the maximum output power available from an 8662A (with overrange capability to +16 dBm) using an external doubler is between +1 and +5 dBm. For additional power, external amplification may be added after the doubler.

Much information can be gained from studying graphs relating conversion loss and drive level (Figure 4). Frequency doublers are generally specified for operation at input power levels in the range of constant conversion loss, shown at the right of the graph. Typically this dictates a minimum drive level of +10 dBm. In this range the full 8662A output resolution of 0.1 dB can be realized and the doubled output level is equal to the 8662A output level minus the doubler conversion loss. The absolute level accuracy is thus equal to the specified ±1 dB 8662A level accuracy plus any uncertainty in the measured doubler conversion loss at the frequency of operation. In addition, an impedance mismatch between the 8662A output and the doubler input will result in a small uncertainty due to mismatch error. For the combination of the 8662A and 11721A, this error will typically be much less than 0.5 dB, and can be further reduced by inserting a 3 dB attenuator (HP 8491A Option 003) between the generator and doubler.

To obtain a wider range of output power with full resolution at a particular frequency, set the 8662A output power level in the range of constant doubler conversion loss and add enough post-doubler attenuation to achieve the desired output level. For example, suppose that a 2 GHz signal at -28 dBm is desired, and the doubler has 11 dB loss in the region of constant conversion loss (Figure 5). Just set the 8662A for a 1 GHz output at +13 dBm and add 30 dB of attenuation after the doubler. The doubled output level can be varied a few dB around -28 dBm with the 0.1 dB resolution of the synthesizer. With the proper combination of output level setting and attenuation, the 8662A doubled output level can be extended downward with full resolution as far as the application requires.

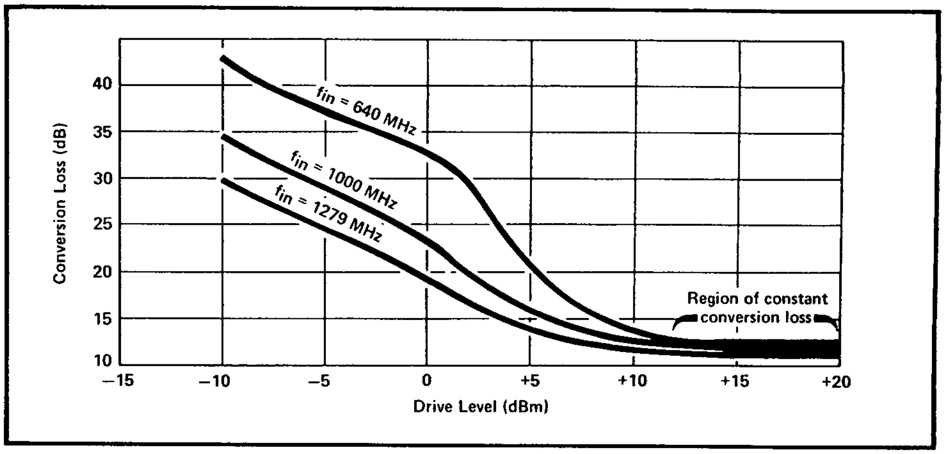

Figure 4. Typical 11721A conversion loss vs. drive level.

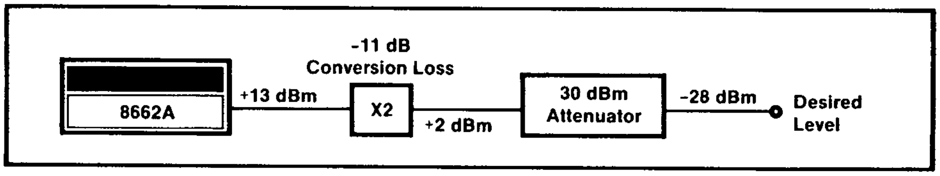

Figure 5. Use of post-doubler attenuation to achieve desired level with full output resolution.

In the remote mode under computer control, an extension of this procedure can provide accurate output levels across the entire doubled frequency band from 1280 to 2560 MHz. First, characterize the doubler to be used for variations in conversion loss with frequency at an input level of +13 dBm, for example. Then store this information in the computing controller's memory in the form of a look-up table. A desired amplitude can be entered into the controller and, using a software correction routine and external programmable attenuators, the controller can automatically set the proper combination of 8662A amplitude and post-doubler attenuation. The absolute level accuracy of this system, which is limited by the accuracy of the programmable attenuators and the accuracy and extent of the data in the look-up table, tends to degrade at lower output levels due to accumulating attenuator inaccuracies.

Modulation

To fully understand the effects of frequency doubling on the spectral purity of the 8662A, it is instructive to look first at its effects on modulation.

Amplitude Modulation. Frequency doubling has a major effect on AM performance. Since the doubler's output level is not a linear function of its input level (see Figure 4), changes in RF amplitude that constitute amplitude modulation at the doubler input are not faithfully reproduced at the output. However, if slightly increased AM distortion can be tolerated, the 8662A can be amplitude modulated at low depths. For example, at an output level of +13 dBm, modulating at depths less than 20% will typically result in less than 3% AM distortion. The level of incidental FM (FM caused by amplitude modulating) also rises rapidly with increasing modulation depth.

Frequency Modulation. Unlike amplitude modulation, frequency modulation suffers no significant adverse effects from frequency doubling. The main consideration is making appropriate allowance for the fact that the peak deviation doubles along with the carrier frequency.

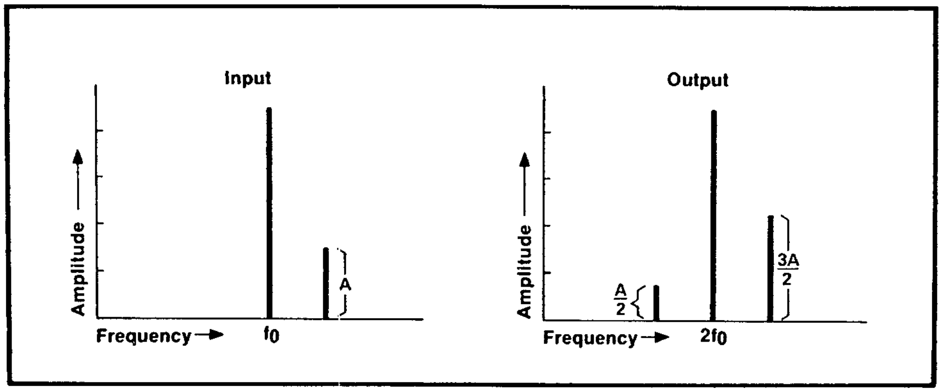

Figure 6. The effect of frequency doubling on spurious signals.

Spectral Purity

Spurious Signals. Single-sided spurious signals in the output of the 8662A may be thought of as a combination of low mod index AM and FM with rates equal to the spacings between the spurious signals and the carrier. While frequency doubling has little effect on the low depth AM, it doubles the modulation index of the FM by doubling the deviation. Combining the effects of doubling on these two modulations produces a net effect of increasing the level of a spurious signal by 3.5 dB. In addition, a new spurious signal appears on the opposite side of the carrier at the same offset as the original spurious signal but at a relative level 6 dB lower than the original spurious signal. This effect, shown in Figure 6, results from the broadband response of the doubler and occurs regardless of the spacing between the original spurious signal and the carrier.

In practice, most signal generator spurious signals are double-sided since they tend to be caused mainly by FM. Applying the effect illustrated in Figure 6, it can be shown that frequency doubling may increase the double-sided spurious signal level as much as 6 dB, depending upon the relative amounts of AM and FM present.

Harmonics. While the harmonic content of the output of a doubler is characteristically quite high, harmonics in the output of the signal generator tend to increase the levels of the f/2, 3f/2, 5f/2, . . . doubler products.

The signal generator harmonics can be thought of as spurious signals whose levels increase by 6 dB in the doubling process. These signals are known as doubler feedthrough and add vectorially with the harmonics generated by the doubler itself. Since the 8662A harmonics are guaranteed to be more than 30 dB below the carrier, the doubler feedthrough is insignificant compared to the f/2, 3f/2, 5f/2, . . . doubler products generated by the doubler itself.

Subharmonics in the output of the source can cause f/4, 3f/4, 5f/4, . . . doubler products. Since the 8662A subharmonics are guaranteed to be more than 75 dB below the carrier, these doubler products are insignificant compared to the f/2, 3f/2, 5f/2, . . . doubler products.

SSB Phase Noise. Considering the effect of doubling on frequency modulation and interpreting phase noise as low depth phase modulation of the carrier by noise, it comes as no surprise that the single sideband phase noise level is increased by 6 dB in the doubling process. Even at this increased level, the frequency doubled 8662A offers superb phase noise performance, particularly close to the carrier.

Digital Sweep

The digital sweep characteristics of the 8662A are not adversely affected by frequency doubling. Frequency related parameters are simply doubled in magnitude. These include the center, span, start, and stop frequencies as well as the step size and marker frequencies.

The 8662A sweep function is a useful tool for evaluating the performance of an external frequency doubler. Set up a slow sweep from 640 MHz to 1279 MHz at +16 dBm and view the doubler output on a spectrum analyzer. The analyzer will display the maximum doubled frequency output level available from the 8662A.

Doubled Performance Characteristics

Listed below are the typical performance characteristics that can be expected when operating the 8662A with a frequency doubler such as the 11721A. These performance characteristics are shown to provide useful information about a frequency doubled 8662A and may vary depending on the doubler used.

FREQUENCY

Range: 1280-2560 MHz (2559.9999996 MHz).

Resolution: 0.4 Hz.

Accuracy and stability: same as reference oscillator in undoubled mode.

Frequency switching speed: same as undoubled mode, except RF settling time is 250 μs to be within 2 kHz and 400 μs to be within 200 Hz of final frequency.

SPECTRAL PURITY

Residual SSB phase noise in 1 Hz BW at 2556 MHz f_c:

Offset	Ø Noise
10 Hz	-88 dBc
100 Hz	-100 dBc
1 kHz	-109 dBc
10 kHz	-120 dBc
100 kHz	-121 dBc

SSB Broadband noise floor in 1 Hz BW at >3 MHz offset from carrier at output levels greater than +10 dBm: <-134 dBc.

Spurious signals: generally increase by 6 dB; see text.

OUTPUT

Power loss due to doubler conversion loss: see text.

Impedance: depends on doubler used and varies with drive level and frequency.

Reverse power protection: subjecting the doubler to high reverse RF power will most likely damage it. The 8662 will remain protected up to 30 watts.

SWR: depends on doubler used and varies with drive level and frequency.

Level switching speed: same as undoubled mode.

AMPLITUDE MODULATION

Generally degraded except at very low depths; see text.

FREQUENCY MODULATION

FM rates: same as undoubled mode.

Maximum peak deviation:

AC mode: 400 kHz or $f_{mod} \times 2000$, whichever is smaller.

DC mode: 400 kHz.

FM resolution: for deviations <20 kHz, 200 Hz; for deviations >20 kHz, 2 kHz.

Incidental AM: same as undoubled mode.

Indicated FM accuracy: ±6% of reading plus 20 Hz (external AC rates).

FM distortion: same as undoubled mode.

Center frequency accuracy and long term stability:

AC FM: same as CW mode.

DC FM: center frequency accuracy is ±40 kHz; center frequency stability is ±800 Hz/h.

DIGITAL SWEEP

Frequency related parameters are doubled; see text.

HP-IB* System for Convenient Doubling Control

The HP-IB system shown in Figure 7 provides a means for quickly and easily obtaining a desired frequency, output level, and modulation from the 8662A from 10 kHz to 2.56 GHz. The 9825A system software example (Figure 8) lists a simple series of subroutines that can be used to command the 8662A, programmable attenuators, and coaxial switches to the settings required to achieve the desired RF performance. Spacing and comments have been included for clarification.

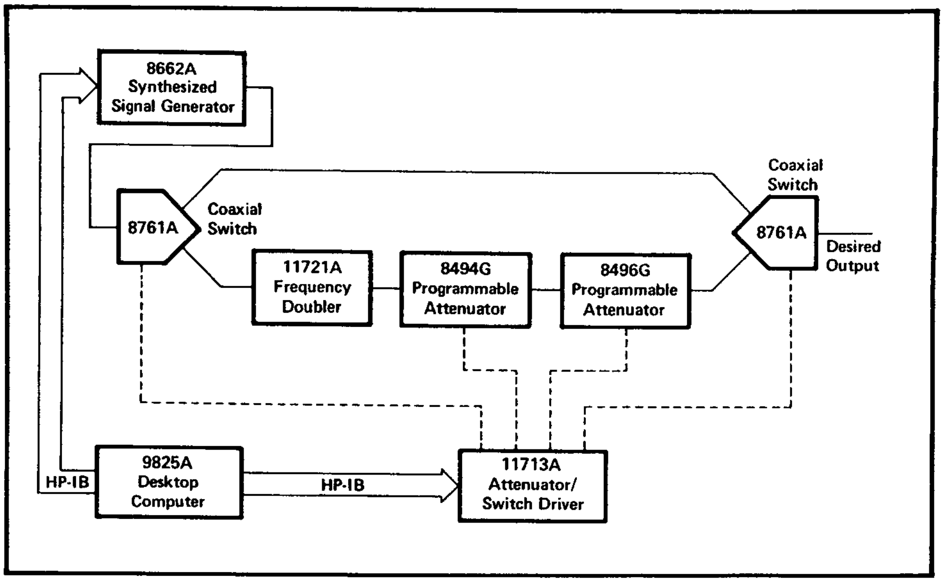

Figure 7. HP-IB System for convenient doubling control.

The software divides logically into 10 subroutines corresponding to various 8662A front panel functions, each accessed by a 9825A special function key. The special function keys are assigned as follows:

Function	Key	Contains Command
Frequency	f_0	*gsb "FREQUENCY"
Amplitude	f_1	*gsb "AMPLITUDE"
AM	f_2	*gsb "AM"
FM	f_3	*gsb "FM"
Internal 400 Hz	f_4	*gsb "INTERNAL 400 Hz"
Internal 1kHz	f_5	*gsb "INTERNAL 1kHz"
External AC	f_6	*gsb "EXTERNAL AC"
External DC	f_7	*gsb "EXTERNAL DC"
Modulation off	f_8	*gsb "MODULATION OFF"
Amplitude off	f_9	*gsb "AMPLITUDE OFF"

Special function key overlays (HP part number 7120-4802) are available for the 9825A so that the operator can label the keys with the 8662A functions they control.

Program line 11, "ldk 1", automatically loads these commands into the special function keys if they have already been recorded on tape file 1 using the "Record Keys" statement. Since their operation is transparent to the user, these special function keys essentially replace all of the FUNCTION and MOD keys on the 8662A keyboard. For example, to set a frequency of 2.456 GHz, press **f_0 2.456 CONTINUE** on the 9825A. The controller software recognizes the entry as a "doubled" frequency, divides 2.456 in half, and commands the 8662A to this frequency. If a frequency less than 1280 MHz is entered, the coaxial switches switch the doubler and attenuators out of the system and the controller commands the 8662A directly to the entered frequency.

The amplitude routine is based upon the output level control scheme suggested in the previous section on output power. If a "doubled" frequency has been entered, the controller uses a look-up table (program lines 7 through 9, abbreviated for the purpose of this example) to obtain the proper doubler conversion loss factor for the frequency of operation. The controller then sets the 8662A level between +12 and +13 dBm and calculates and sets any required attenuation using programmable attenuators. Since the conversion loss factor obtained from the look-up table corresponds to the value of frequency F stored in the controller, it is necessary to set the frequency of operation prior to setting an amplitude desired at that frequency. If a frequency less than 1280 MHz is entered, the controller just sets the 8662A to the amplitude entered.

*HP-IB is Hewlett-Packard's implementation of the IEEE standard 488-1975.

The range of amplitude settings available in the undoubled frequency mode using this routine is +16 to -139.9 dBm. The range of amplitude settings available in the "doubled" frequency mode lies between a maximum of (12.9-Q) dBm to a minimum of (-109-Q) dBm, where Q is the value of conversion loss stored in the look-up table. For this routine, the 8662A level is varied between +12 and +13 dBm so that it can provide the maximum doubler drive possible and still remain in the 8662A "level corrected" mode. (The 8662A itself uses a level correction scheme between +13 and -120 dBm to achieve ±1dB absolute level accuracy.)

The program has provisions for alerting the operator when entries outside of the expected ranges occur. Although the controller will accept AM depths up to 95%, the user should keep in mind the performance limitations imposed by frequency doubling outlined earlier. To avoid AM distortion above 3% at frequencies above 1280 MHz, only AM depths less than 20% should be entered.

Summary

Frequency doubling allows the 8662A to be used in applications at frequencies between 1.28 and 2.56 GHz as long as certain technical limitations are recognized. To summarize these limitations, output power drops at least 11 dB and the levels of the harmonics greatly increase; phase noise and spurious levels increase by 6dB; amplitude modulation distorts except at very low depths, while frequency modulation simply doubles in deviation.

Some of these limitations can be overcome once the particular doubler in use is characterized for its conversion loss over the frequency range of operation. In particular, an HP-IB calculating controller using simple driver routines can both compensate for such limitations and serve as a transparent interface for 8662A manual operation.

The general principles presented in this application note apply not only to doubling frequency of the 8662A but also to doubling the frequency of any other signal source, provided it has enough power to drive a frequency doubler. Likewise, these principles apply not only to the 11721A Frequency Doubler but also to passive frequency doublers in general. However, the 11721A is designed for use with the 8662A and is optimized for low conversion loss and spurious at input frequencies from 640 to 1280 MHz.

```
0: "8662A/11721A APPLICATION ROUTINE":
1: "Device 719 will be referred to as the 8662, etc.":
2: dev "8662",719,"11713",724
3: "Reset the 8662":
4: clr 719
5: "Dimensionalize variables and load look-up table T":
6: dim A$[16];dim T[11]
7: 13→T[1];13.4→T[2];13.3→T[3];13.4→T[4]
8: 13.2→T[5];13.8→T[6];12.5→T[7];12.2→T[8]
9: 12.6→T[9];12.9→T[10];13.2→T[11]
10: "Load special function keys with gsb commands":
11: ldk 1
12: dsp "Use special function keys";stp
13:
14:
15: "FREQUENCY":
16: 0→E
17: "Enter and display desired frequency in GHz":
18: ent "Frequency(GHz)",F
19: fmt ,"Frequency ",f11.9," GHz"
20: wrt 0,F
21: "Check to ensure entry is within proper limits":
22: if F<2.56;if F>=.000001;gto 25
23: beep;dsp "ILLEGAL ENTRY";stp
24: "If undoubled frequency desired, switch doubler out of system":
25: if F<1.28;1→E;F→G;wrt "11713","A90";gto 29
26: "If doubled frequency is desired, switch in doubler":
27: F/2→G;wrt "11713","B90"
28: "Set 8662 frequency":
29: fmt 1,"FR",f12.10,"GZ"
30: wrt "8662.1",G;stp
```

Figure 8. 8662A/11721A application routine.

```
31:
32:
33: "AMPLITUDE":
34: "Enter desired amplitude in dBm":
35: ent "Amplitude(dBm)",L
36: "Check to ensure entry is within proper limits":
37: if L<=16;if L>=-139.9;gto 40
38: beep;dsp "ILLEGAL ENTRY";stp
39: "Display entry":
40: fmt ,"Amplitude ",f6.1," dBm"
41: wrt 0,L
42: "If undoubled frequency was desired, set 8662 amplitude":
43: if E=1;L→C;gto 68
44: "Obtain conversion loss for desired frequency from look-up table":
45: for I=1 to 11
46: 1.152+I.128→J
47: F-J→X
48: if abs(X)<=.064;T[I]→Q;gto 51
49: next I
50: "Compute required post-doubler attenuation":
51: -1(12-(L+Q))→Z
52: frc(Z)→D
53: -lint(Z)→Z
54: "Set required post-doubler attenuation":
55: "B1B2B3B4B5B6B7B8"→A$
56: Z→Y;if Z<12;gto 61
57: if Y-40>=0;Y-40→Y;"A"→A$[13,13]
58: if Y-40>=0;Y-40→Y;"A"→A$[15,15]
59: if Y-20>=0;Y-20→Y;"A"→A$[11,11]
60: if Y-10>=0;Y-10→Y;"A"→A$[9,9]
61: if Y-4>=0;Y-4→Y;"A"→A$[5,5]
62: if Y-4>=0;Y-4→Y;"A"→A$[7,7]
63: if Y-2>=0;Y-2→Y;"A"→A$[3,3]
64: if Y-1>=0;"A"→A$[1,1]
65: wrt "11713",A$
66: "Compute and set 8662 amplitude":
67: D+12→C
68: fmt 2,"AP",f4.1,"+D"
69: fmt 3,"AP",f6.1,"-D"
70: if C<0;wrt "8662.3",C
71: wrt "8662.2",C;stp
72:
73:
74: "AM":
75: "Enter desired depth of AM in percent":
76: ent "AM Percent",P
77: "Check to ensure entry is within proper limits":
78: if P>=0;if P<=95;gto 81
79: beep;dsp "ILLEGAL ENTRY";stp
80: "Display entry":
81: fmt ,"AM ",f4.1," Percent"
82: wrt 0,P
83: "Set 8662 AM depth":
84: fmt 3,"AM",f4.1,"PC"
85: wrt "8662.3",P;stp
86:
87:
```

Figure 8. 8662A/11721A application routine (continued).

```
88: "FM":
89: "Enter desired FM deviation in kHz":
90: ent "FM Deviation(kHz)",M
91: "Check to ensure entry is within proper limits":
92: if M>=0;if M<=200;gto 96
93: if M>=0;if M<=400;if E=0;gto 96
94: beep;dsp "ILLEGAL ENTRY";stp
95: "If undoubled frequency was desired, set 8662 deviation":
96: if E=1;M→N;gto 100
97: "If doubled frequency was desired, divide deviation in half":
98: M/2→N
99: "Set 8662 deviation":
100: fmt 4,"FM",f3.1,"KZ"
101: fmt 5,"FM",f3.0,"KZ"
102: if N>=10;gto 105
103: wrt "8662.4",N
104: gto 107
105: wrt "8662.5",N
106: "Display entry":
107: fmt ,"FM ",f5.1," kHz"
108: wrt 0,M;stp
109:
110:
111: "INTERNAL 400 Hz":
112: "Set 8662 modulation source to internal 400 Hz":
113: wrt "8662","M1"
114: dsp "Internal 400 Hz";stp
115:
116:
117: "INTERNAL 1 kHz":
118: "Set 8662 modulation source to internal 1 kHz":
119: wrt "8662","M2"
120: dsp "Internal 1 kHz";stp
121:
122:
123: "EXTERNAL AC":
124: "Set 8662 modulation source to external AC":
125: wrt "8662","M3"
126: dsp "External AC";stp
127:
128:
129: "EXTERNAL DC":
130: "Set 8662 modulation source to external DC":
131: wrt "8662","M4"
132: dsp "External DC";stp
133:
134:
135: "MODULATION OFF":
136: "Turn 8662 modulation off":
137: wrt "8662","M0"
138: dsp "Modulation Off";stp
139:
140:
141: "AMPLITUDE OFF":
142: "Turn 8662 amplitude off":
143: wrt "8662","A0"
144: dsp "Amplitude Off";stp
```

Figure 8. 8662A/11721A application routine (continued).

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