graphical selection
of mixer frequencies

See, at a glance, any spurious that might cause problems

Selecting the proper mixer frequencies can be a real problem. Often a lengthy trial-and-error procedure yields unsatisfactory results because of too many spurious signals in the passband. The graphical technique described here will deliver more accurate results in less time and with less difficulty. Some plotting is required, and a simple calculator will help with the math.

background

When two frequencies, f_1 and f_2, are combined in a mixer, the nonlinear action of the mixer produces a series of products that have the form:

$$P = Mf_1 + Nf_2 \tag{1}$$

where M and N are positive or negative integers, and P is the frequency of the combination. In ordinary mixer use, a bandpass or low-pass filter removes all but the desired product P, called the desired output frequency, or f_0. Generally, the larger M and N are, the smaller the amplitude of P. Then, too, the farther a particular P is from f_0, the less interference it will cause. One way to measure the frequency separation is to use the percentage separation, S, given by:

$$S = 100\frac{P - f_0}{f_0} \tag{2}$$

Now, if f_1 is always chosen as the smaller of f_1 and f_2, then the ratio f_1/f_2 can be given by:

$$f_1/f_2 = \frac{-S + 100(N - 1)}{S - 100(M - 1)} \tag{3}$$

where $f_0 = f_2 + f_1$

$$\text{or } f_1/f_2 = \frac{S + 100(1 - N)}{S + 100(1 + M)} \tag{4}$$

where $f_0 = f_2 - f_1$

Equations 3 and **4** are used to plot the spurious components, or spurs; **eq. 3** is used for sum spur charts, and **eq. 4** is used for difference spur charts. The case for N = M appears as a vertical line on the sum chart at S = 100(N − 1), and the case for N = −M appears as a vertical line on the difference chart, also at S = 100(N − 1).

conversion of fixed frequencies

Figure 1 shows a graph with several spur plots for f_1 = 3 MHz and f_2 = 18 MHz. Which ones need to be plotted? Well, that depends on how stringent your requirements are. Once you determine how low the spurs must be, you need plot only the spurs which

By G. Timothy Anderson, W2HVN, 902 Ashburn Street, Herndon, Virginia 22070

table 1. Typical values of spurious levels in a double-balanced mixer. Values shown are in dB below desired output. Here, f_2 is the local oscillator frequency.

	f_2	$2f_2$	$3f_2$	$4f_2$	$5f_2$	$6f_2$
$6f_1$	90	90	90	90	90	90
$5f_1$	80	90	71	90	68	90
$4f_1$	90	86	80	88	85	86
$3f_1$	64	69	50	77	47	74
$2f_1$	73	74	70	71	64	69
f_1	0	35	13	40	24	45

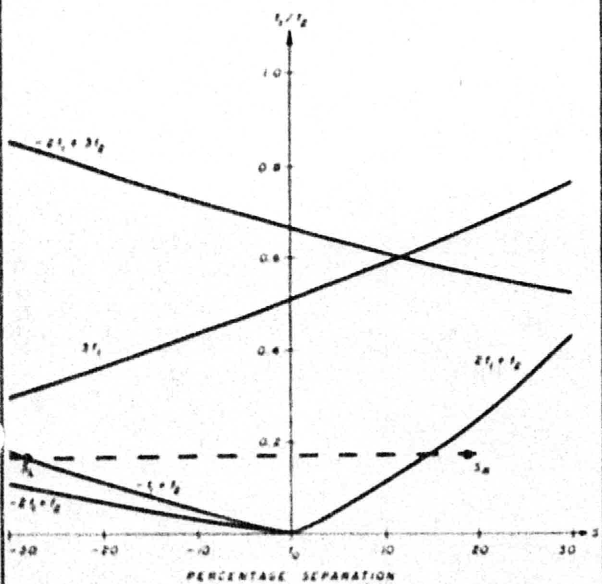

fig. 1. Spur chart for fixed-frequency conversion example: $f_0 = f_2 + f_1$.

might exceed that level. Some manufacturers provide tables of spur levels for different values of M and N.* **Table 1** shows some typical values.

To use a spur chart such as shown in **fig. 1**, you must somehow represent the bandwidth of the system. In **fig. 1**, this is done by plotting a dashed line representing an output frequency range for a given f_1 and f_2. The end points are denoted by S_L and S_R.

$$S_L = 100\frac{f_{OL} - f_O}{f_O} \qquad (5)$$

and

$$S_R = 100\frac{f_{OR} - f_O}{f_O} \qquad (6)$$

*Mini-circuits, P.O. Box 166, Brooklyn, New York 11235, and Watkins-Johnson Company, 3333 Hillview Avenue, Palo Alto, California 94306, for example, furnish tables of this kind.

where f_{OL} and f_{OR} are, respectively, the low and high ends of the output passband. S_L and S_R are the abscissa values; the ordinate value, f_1/f_2, is already known. Refer again to **fig. 1**. If, for example, an output passband of 10 MHz is chosen, from 15 MHz to 25 MHz, then $S_L = -28.6$ and $S_R = 19.0$. The ordinate is $f_1/f_2 = 3/18 = 0.17$. Note that two of the spurs intersect the bandwidth line, $-f_1 + f_2$ and $2f_1 + f_2$. This means that these two spurs are in-band harmonics. If the bandwidth was narrowed to, say, 5 MHz (18.5 MHz to 23.5 MHz), then the end points would be closer together and the spurs would be outside the passband. Note that if the slope of the filter is known, the attenuation of the out-of-band spurs can be calculated because **fig. 1** indicates how far out on the filter skirt the spurs are located. Of course, there is still the problem of the 18-MHz signal in the output. It, too, is a spur, and must be taken into consideration since it will be down probably no more than 50 dB.

conversion of bands of frequencies

Now that I've discussed a specific case with fixed frequencies, let's consider the general case — converting one band of frequencies to another band of frequencies where f_1, f_2, and f_0 have different bandwidths. Suppose you want to convert 300 MHz ± 10 MHz to 200 MHz ± 15 MHz by mixing with 100 MHz ± 5 MHz. You have $f_{1L} = 95$ MHz, $f_{1H} = 105$ MHz, $f_{2L} = 290$ MHz, $f_{2H} = 310$ MHz, $f_{0L} = 185$ MHz, and $f_{0H} = 215$ MHz. First you'll outline the region you want to be free of spurs. (In general, this takes the shape of a hexagon with slightly curved sides. Since the curvature is slight, you can assume straight lines to ease the computations and still retain good accuracy.) This is done by using **eqs. 5** and **6** to calculate the corner points. Different combinations of the high and low extremes of f_1 and f_2 are used to find each particular f_0. Here's how to do it (remember — $f_0 = f_2 - f_1$ here).

Calculate: S_L using f_{1L} and f_{2H}
S_L using f_{1H} and f_{2H}
S_L using f_{1H} and f_{2L}
S_R using f_{1H} and f_{2L}
S_R using f_{1L} and f_{2L}
S_R using f_{1L} and f_{2H}

These calculations produce the numbers shown in **table 2**, and the six points 1 through 6 in **fig. 2**; the dashed lines define the desired spur-free area. For this combination of frequencies, two spurs cross the hexagon. Either of two things can be done to resolve this. You can change the frequencies or try a high-level mixer with reduced drive, which will result in fewer spurs.

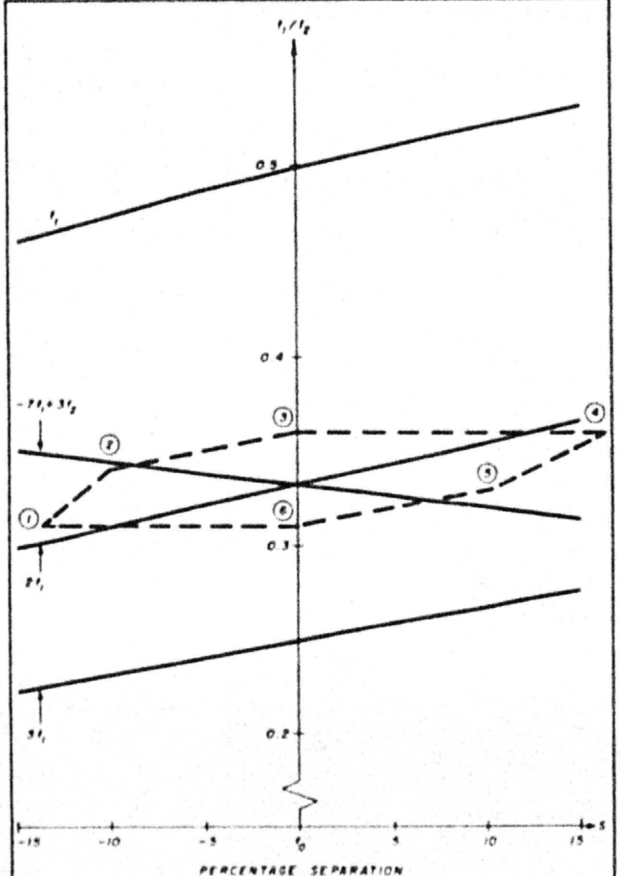

fig. 2. Spur chart for conversion of bands of frequencies — $f_0 = f_2 + f_1$. The circled numbers (1-6) are those referred to in the text and listed in *table 2*.

table 2. Values for points 1 through 6 in *fig. 2*.

point	S_L	S_R	f_1/f_2
1	−13.95	—	0.31
2	−9.76	—	0.34
3	0.00	—	0.36
4	—	16.22	0.36
5	—	10.26	0.33
6	—	0.00	0.31

As a final example, let's try upconverting 28-32 MHz to 50-54 MHz by mixing with 22 MHz. Here, f_1 has zero bandwidth ($f_{1L} = f_{1H}$). This produces the dashed line (---) shown in **fig. 3**. Two things are evident: the hexagon is now a quadrilateral (because one of the frequencies, f_1, has zero bandwidth), and one of the spurs cuts through this quadrilateral. If you select a different combination — say, $f_1 = 22.5$ MHz and $f_2 = 27.5 - 31.5$ MHz — then you get a quadrilateral as shown by the dashed-and-dotted line (---) in **fig. 3**. This new area is spur-free so the filtered output will be free of spurs.

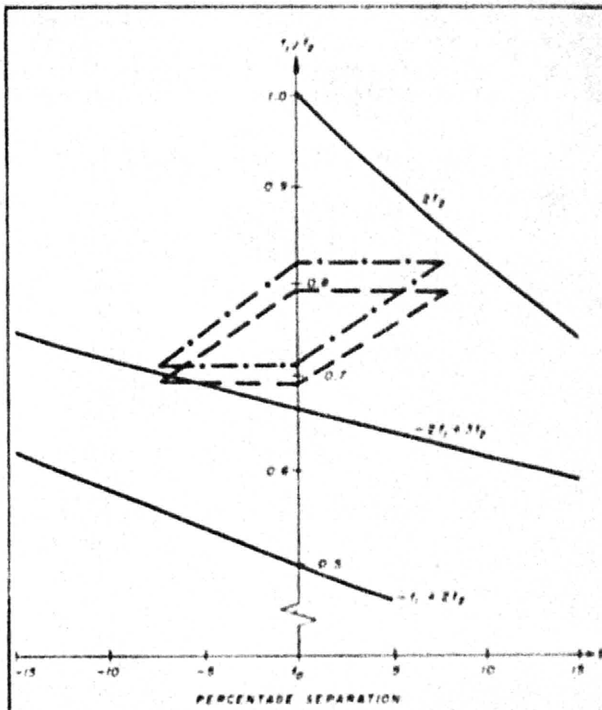

fig. 3. Spur chart with f_1 having zero bandwidth — $f_0 = f_2 + f_1$.

appendix

Equation 2 can be rewritten to give:

$$P = \frac{f_0 S}{100} + f_0 \qquad (7)$$

For the case when $f_0 = f_2 + f_1$, inserting **eq. 1** in **eq. 7** yields $P = M(f_0 - f_2) + Nf_2$, or

$$f_2 = \frac{P - Mf_0}{N - M} \qquad (8)$$

Equation 8 can be used in the expression for f_1/f_2 to eliminate f_2:

$$f_1/f_2 = \frac{f_0 - f_2}{f_0} = \frac{Nf_0 - P}{P - Mf_0} \qquad (9)$$

Now, if **eq. 7** is inserted into **eq. 9**:

$$f_1/f_2 = \frac{Nf_0 - (f_0S/100 + f_0)}{f_0S/100 + f_0 - MF_0}$$

$$= \frac{-S + 100(N - 1)}{S - 100(M - 1)} \qquad (3)$$

If $f_0 = f_2 - f_1$, a similar procedure gives:

$$f_2 = \frac{P + MF_0}{N + M} \qquad (10)$$

$$f_1/f_2 = \frac{P - Nf_0}{P + Mf_0} \qquad (11)$$

and

$$f_1/f_2 = \frac{S + 100(1 - N)}{S + 100(1 + M)} \qquad (4)$$

reference

1. M.Y. Huang et. al., "Select Mixer Frequencies Painlessly," *Electronics Design*, No. 8, April 12, 1976, pages 104-109.

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