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Computer Improves Receiver Design

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Summary

This paper will review the processes of spurious response generation in land-mobile receivers. The various types of spurious responses will be discussed. Formulas required to calculate the spurious response frequencies will be presented, and the use of a computer for spurious-response frequency prediction will be outlined. These computer spurious-response frequency predictions can be used as an aid in designing systems to avoid spurious. In addition, these predictions may be used by the receiver designer to minimize spurious. Several different methods of minimizing receiver spurious responses will be discussed since the various spurious mechanisms require different methods of reduction.

Introduction

Despite today's generally excellent receiver spurious response rejection, spurious still cause us trouble. This is particularly true at multi-system radio sites, such as mountain tops, where even a 100db receiver spurious response rejection may not be sufficient to prevent this type interference. Because of situations such as these, the systems engineer should have as keen an interest in receiver spurious as the receiver designer has.

In this paper, we will present a method of using an electronic computer for predicting the spurious responses of receivers. The use of a computer in this manner can be a powerful tool in the hands of either the receiver designer or the systems engineer for it not only will allow identification of a spurious but also will pinpoint the mechanism by which a spurious is created. Armed with complete information of this sort, it should then be possible for the engineer to make intelligent decisions as to the treatment necessary to eliminate the interference.

General Considerations

The International Dictionary of Physics and Electronics defines a spurious response as "Output from a receiver due to a signal or signals having frequencies other than that to which the receiver is tuned". In this paper, we will restrict our definition of a spurious response somewhat more. We will assume only a single R.F. signal, thus removing intermodulation from consideration. Intermodulation interference, of course, will be of increasing importance to the system design engineer, but that is another problem and must be covered by a separate paper. Basically, our consideration will be limited to spurious resulting from the one or more frequency conversions present in the modern land mobile receiver.

Since spurious are a result of the mixing process, one can expect to find them associated with each conversion. Perhaps then, a receiver with a larger number of conversions is not automatically better than one with fewer conversions. In fact, the reverse is generally true. All other specifications being equal, the receiver with the fewer conversions should be better by virtue of the lower number of spurious responses possible. Of course, it is usually possible, by adding a suitable amount of selectivity preceeding a mixer, to reduce the spurious contributed by that mixer to negligible proportions (i. e. - 100db down), but it is never possible to eliminate all of them. One of the prime reasons for the use of more than two conversions in a receiver is the manufacturers' inability to provide economically the necessary R.F. and I.F. selectivity at the frequencies required for a double or single conversion receiver.

Since the processes of spurious generation are identical for the various mixers in a receiver, we will explain the spurious generation processes using the first mixer. Keep in mind that basically the same processes also apply to the other conversions in the receiver.

For any particular mixer, most spurious responses can be described by a single mathematical formula, since any combination of input signal harmonic and local oscillator harmonic which has a difference equal to the intermediate frequency may produce a response if the signals are strong enough. This formula is:

$$\left| N \times R.F. - L \times XTAL \right| = I.F.$$

which can also be written:

$$N \times R.F. - L \times XTAL = \pm I.F. \qquad (1)$$

WHERE:

L and N are integers.

R. F. is an input signal to the mixer.

XTAL is the local oscillator(not necessarily the injection frequency).

I.F. is the intermediate frequency to which the mixer in question converts.

One combination of L and N is selected to produce the desired mixing action. Generally, N will be 1 for this condition. L also may be 1, but may have other values in receivers with crystal controlled local oscillators.

Solving equation (1):

$$R.F. = \frac{L\ (XTAL) \pm I.F.}{N} \qquad (2)$$

In addition to the spurious described by this formula, there is one other type possible in a multi-conversion receiver. This spurious is known as a "Tweet" spurious, and it occurs when a harmonic of the second conversion oscillator beats with a harmonic of the first conversion oscillator to produce the I.F. This type of spurious occurs only at a few discreet operating frequencies for any particular receiver. It is generally considered to be a manufacturers' problem and will not be treated further in this paper.

To aid in our understanding of different types of spurious, examples will be constructed using the first mixer of a receiver with the following constants:

Frequency of Operation(F.O.) =	170 Mc
Injection Frequency =	162 Mc
I.F. =	8 Mc
Crystal Frequency(XTAL) =	16.2 Mc
Crystal Multiplier(K) =	10 (x5 x 2)

Using the constants for this receiver and solving formula (2) for the frequency of operation rather than a spurious gives:

$$(R.F.) = \frac{(10)\ \ (16.2) \pm 8}{1}$$

Using + 8 Mc (low side injection):

$$R.F. = 170$$

The spurious described by formula (2) will be of different nature and have different characteristics depending on the numbers used for L, and N. Several possible groups of spurious are as follows:

Fixed Frequency Spurious Response

The only spurious likely under this category is the I.F. feed thru spurious which occurs if N = 1, R.F. = I.F. and L = 0. In our sample receiver, this response could occur at 8 Mc.

Fixed Separation Spurious Responses

These responses always occur at a fixed number of Kc or Mc from the desired signal and always on the same side.

The Image - The most well known of the fixed separation spurious is the image. If 154 Mc is applied to our sample receiver, it will produce the I.F. since the difference between the injection, 162 Mc, and 154 Mc is 8 Mc. The solution of formula (2) above would have yielded this answer if we had selected the minus sign. It is obvious that unless selectivity is provided, the receiver will respond as well to 154 Mc as it does to 170 Mc.

The One-Half I.F. Family - Using our sample receiver, if we make the following substitutions in Formula (2):

Let L = 20, and N = 2

$$\text{then: } R.F. = \frac{(20)\ \ (16.2) + 8}{2}$$

$$R.F. = \frac{324 \quad + 8}{2}$$

R.F. = 166 (166 is I.F./2 below 170 Mc)

This spurious is known as the one-half I.F. The production of this spurious depends on the mixer generating the second harmonics of both the spurious frequency and the injection frequency. If the injection is low in second harmonic content, this spurious is normally 40 to 50 db down, even if no R.F. selectivity is used. There is a whole family of spurious similar to the one-half I.F. These are the one-third I.F., one-fourth I.F., etc. Since these fall further off the desired frequency and involve higher order harmonics, they are generally quite well suppressed by the selectivity provided to reject the image and one-half I.F.

Spurious Responses Related To But Not a Fixed Separation From The Desired Frequency

These responses may occur almost anywhere in relation to the desired signal. However, they are most troublesome when they fall within the bandpass of the selectivity protecting the mixer. Since these spurious involve high order harmonics and/or injection at other than the normal injection frequency, they are naturally quite well suppressed.

The Oscillator Harmonics Plus or Minus the I.F. - Our sample receiver could possibly respond to 73 or 89 Mc as follows:

Let L = 5, and N = 1

$$\text{then: } R.F. = \frac{5\ (16.2)\ \ \pm 8}{2}$$

$$R.F. = 81 \pm 8$$

R.F. = 73 or 89 Mc

These then would involve the fifth harmonic of the crystal rather than the 10th. Responses of this type are possible at any harmonic of the crystal frequency. Generally, they will be quite weak because of the protection offered by the R.F. selectivity. This type of spurious also can be quite strong if it falls within the R.F. bandpass as in the following example:

Let $L = 11$, and $N = 1$

then: $$R.F. = \frac{(11)\ (16.2)\ - 8}{1}$$

$$R.F. = + 178.2 - 8$$

$$R.F. = 170.2$$

From this it can be seen that a strong spurious can exist at 170.2 Mc if the 11th harmonic of the crystal is allowed to reach the mixer.

General Case - The most general case of our formula involves allowing both N and L to assume values representing higher order harmonics. These spurious also will be somewhat troublesome if they fall within the receiver R.F. bandpass. The following example will illustrate this type:

Let $L = 52$, and $N = 5$

then: $$R.F. = \frac{52\ (16.2) + 8}{5}$$

$$R.F. = \frac{842.4 + 8}{5}$$

$$R.F. = \frac{850.4}{5}$$

$$R.F. = 170.08 \text{ Mc}$$

Figure (1) illustrates the last two examples. The upper portion of the figure illustrates the frequency location of these two spurious for operating frequencies in the 162 to 174 Mc range. At an operating frequency of 170 Mc the spurious fall at + 200 Kc and + 80 Kc as in our examples. As can be seen, at an operating frequency of 168 Mc, no spurious will show up because they fall right on the operating frequency. The lower portion of the curve illustrates typical R.F. selectivity for a high band mobile receiver. The importance of careful selection of the operating frequency used in testing for spurious can be seen from the following example. If 174 Mc (a band-end) is selected, the L = 11 spur will be attenuated about 15 db more than it would be near 168 Mc. In testing for this spurious, a frequency near but not exactly on 168 Mc should be selected. Other spurious mechanisms may require testing at different frequencies to assure that all worst case conditions are covered. The computer analysis to follow assists the receiver designer in locating these test frequencies.

We have now completed our review of the various spurious mechanisms using the first mixer as an example. We have seen that some first mixer spurious fall quite close to the desired frequency while others may be hundreds of Mc removed. However, all close-in spurious are not necessarily first mixer spurious, and confusion can arise here since second and third conversion spurious almost always fall close to the desired frequency as viewed from the receiver front end. For example, let us consider that our sample receiver has a second conversion from 8 Mc to 455 Kc using a second crystal of 8455 Kc. The image associated with this conversion would be at 8910 Kc. This would translate to 910 Kc removed from the desired front end frequency which would be relatively close in. Fortunately, the frequencies of the receiver I.F.'s are generally fixed. Therefore, the second conversion spurious generated are always removed from the desired frequency by the same amount and are readily identifiable. Table 1 illustrates the location of the most common spurious for 455 Kc and 290 Kc low I.F.'s.

TABLE 1
COMMON SECOND CONVERSION
SPURIOUS RELATED TO FRONT END FREQUENCY

LOW I.F. FREQUENCY KC	SECOND CONVERSION HI OR LOW SIDE INJECTION	2ND IMAGE SPURIOUS KC FROM DESIRED	ONE-HALF LOW I.F. SPURIOUS KC FROM DESIRED
455	LOW	-910	-227.5
455	HI	+910	+227.5
290	LOW	-580	-145
290	HI	+580	+145

Computer Program

Up to this point, we have shown examples of spurious responses. As previously stated, any combination of input signal harmonic and local oscillator harmonic which has a difference equal to the intermediate frequency may produce a response if the signals are strong enough. Next, we will derive from equation (2) the formula to be solved by the computer.

$$R.F. = \frac{L\ (XTAL) \pm I.F.}{N} \qquad (2)$$

For programming convenience, it would be desirable to have an equation which relates the spurious frequency to the desired frequency:

$$DSPUR = R.F. - F.O. \qquad (3)$$

WHERE: F.O. is the frequency of operation

To find F.O., let

$$N = 1, \text{ and } L = K \text{ (the crystal multiplier)}$$

Then: $F.O. = K\ (XTAL) + I.F.$ (4)

Substituting (2) and (4) in (3):

$$DSPUR = \frac{L\ (XTAL) \pm I.F.}{N} - (K(XTAL) + I.F.)$$

$$DSPUR = \frac{L}{N}\ (-XTAL) - K(XTAL) \pm \frac{I.F.}{N} - I.F.$$

$$DSPUR = \frac{L - N\ K}{N}\ (XTAL) - I.F. \pm \frac{I.F.}{N} \qquad (5)$$

This equation can readily be programmed on a computer. The computer can be instructed to solve equation (5) for all values of L and N to any desired limit. This will yield a list of all potential spurious responses corresponding to the selected harmonics. Some will be very unlikely because they are far outside the R.F. bandpass of the receiver. To conserve time and paper, the computer can be set to test the magnitude of DSPUR so that only values of DSPUR smaller than a predetermined test limit will be printed. Usually, the RF bandpass of the receiver is a suitable limit for values of N greater than 1. A wider test limit may be used when N = 1. This test limit is called TEST.

To make the program as useful as possible, it can be arranged to compute potential spurious for a complete frequency band. For example, one might decide to check the 450 to 470 Mc band in 2 Mc increments.

This equation is very easy to program in computer language. We chose FORTRAN to use on our G. E. Computer.

The basic equation to be solved is:

$$DSPUR = \frac{L - N\ K}{N}\ (XTAL) - I.F. \pm \frac{I.F.}{N} \qquad (5)$$

F.O., I.F., K and NF (the highest value of N) are read in on the data card.

XTAL is calculated:

$$XTAL = \frac{F.O. - I.F.}{K}$$

Note that I.F. will be negative if the injection frequency is above the operating frequency. The range of L is determined by the test limit and value of N F as follows:

If I.F. is positive, calculate a number,

$$MS = \frac{-\ TEST}{XTAL} \text{ truncated to an integer.}$$

Also, calculate a number,

$$MF = \frac{NF\ (TEST + I.F.)}{XTAL} + 1 \text{ truncated to an}$$

an integer.

If I.F. is negative, calculate,

$$MS = \frac{NF\ (I.F. - TEST) - I.F.}{XTAL} - 1$$

And $MF = \frac{TEST}{XTAL}$, both truncated to integers.

Then: L1 (Starting L) = (N (K) + MS) or 1, whichever is greater,

And L2 (Highest value of L) = N (K) + MF.

The basic equation is now solved for all values of N from 1 to NF and all values of L from L1 to L2 for each F.O. of interest. Each result is tested and if it falls within the range F.O. ± TEST, the result is printed.

The readout is arranged to print the operating frequency, crystal frequency, crystal multiplier, I.F., and test limit for the given problem so that the readout will be a complete record. The potential spurious frequencies are then tabulated along with the relationship to the desired signal, the crystal harmonic involved and the spurious frequency harmonic. Fig's. 2 and 3 show typical readouts.

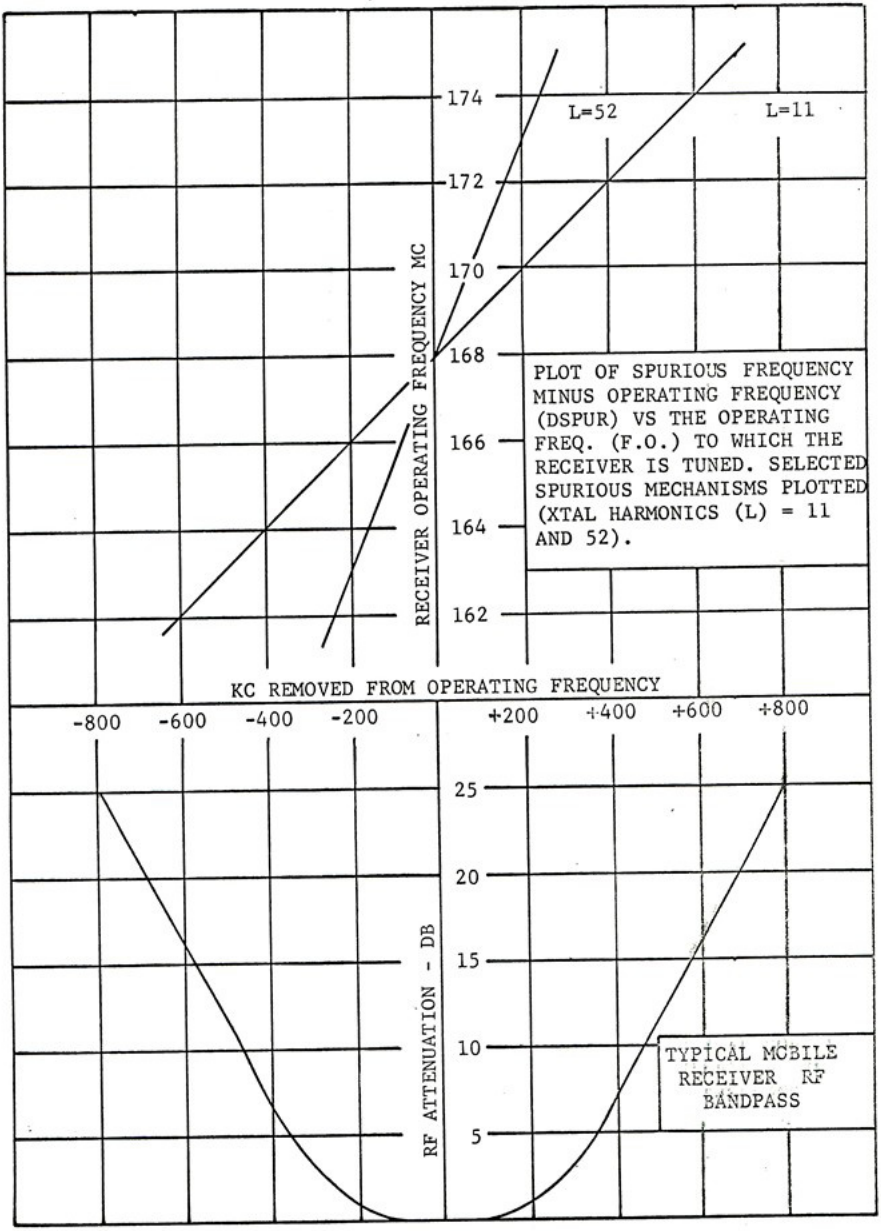
The computed results may be used in several ways. If a particular receiver frequency has been checked by measurement and spurious responses observed, the observed frequencies can be matched with the chart to identify the cause of each response. If the spurious is not identified by the chart, additional frequency sources inside or outside of the receiver should be found such as radiation from a nearby transmitter or coupling from a second oscillator in the receiver. The receiver designer would likely run a chart of an entire frequency band to assist him in finding operating frequencies most likely to show spurious responses. The system designer could use these charts to check actual frequencies being used in an area around a proposed installation of a new receiver against the potential spurious responses of the receiver.

Spurious Reduction Techniques

We have shown how the computer can show where to look for spurious. We have been asked if this will predict relative amplitudes of spurious responses. It will not do so and we believe that it should not. The harmonics generated in the mixer which produce spurious response frequencies in mobile equipment typically fall in the hundreds or thousands of megacycles. Thus, parasitic resonances in electrical parts or mechanical structures may cause unexpected frequencies to be troublesome. In the course of a receiver design, one would first pick I.F.'s and crystal multipliers to minimize the number of harmonics that may cause spurious. Second, one would choose the lowest I.F. consistent with the available R.F. selectivity. This will cause the close-in spurious frequencies to have the highest multiplier and therefore lower energy in the nonlinear device (mixer). Then in the course of building samples, the computer program will point to operating frequencies which are most likely to show problems. The general case type spurious responses tend to group such that they only fall within the R.F. bandpass near certain operating frequencies. Unless testing is carried out near one of these operating frequencies, this type may not be found at all. The band ends rarely coincide with operating frequencies which are likely to show these spurious responses. If spurious are found, the troublesome harmonics are pinpointed. The data will suggest whether parasitic resonances are involved or whether it may be that additional shielding or additional tuned circuits in a certain path may be required.

Occasionally, it turns out that none of these things will help because the offending harmonics are harmonics of the desired inputs to the mixer. In this case, the harmonics are generated in the mixer. There are a few things which can be done to minimize this harmonic generation. One can choose a transistor of relatively low cutoff frequency which would tend to reduce high order harmonics. One can attempt to keep the injection larger than the largest expected spurious signal. This will keep the mixer in a relatively small signal "linear" operating region.

Receiver designers always wish for RF selectivity that has infinite rejection outside the passband, but economics being what they are, we actually must make the best compromise we can with space and cost allocated to R.F. selectivity, multiplier selectivity and I.F. selectivity. At the present state-of-the-art, we can build high I.F. crystal filters economically. The incorporation of these filters in a land mobile receiver moves the major selectivity in the receiver to a point where the adjacent channel and any possible second conversion spurious frequencies are prevented from reaching the second mixer. The use of crystal filters in this manner is a step in the right direction and represents about the economical limit in moving the major selectivity forward in the receiver. For the great mass of receivers in the land mobile service, further improvement in reducing those spurious which fall within the R.F. bandpass and also in reducing intermodulation will come from improving the maximum signal handling capability of the receiver front-end and not from the use of expensive and restrictive R.F. filters.



174
172
170
168
166
164
162
L=52
L=11
RECEIVER OPERATING FREQUENCY MC
PLOT OF SPURIOUS FREQUENCY MINUS OPERATING FREQUENCY (DSPUR) VS THE OPERATING FREQ. (F.O.) TO WHICH THE RECEIVER IS TUNED. SELECTED SPURIOUS MECHANISMS PLOTTED (XTAL HARMONICS (L) = 11 AND 52).
KC REMOVED FROM OPERATING FREQUENCY
-800
-600
-400
-200
+200
+400
+600
+800
25
20
15
10
5
RF ATTENUATION - DB
TYPICAL MOBILE RECEIVER RF BANDPASS

FIG I

PREDICTION OF SPURIOUS FREQUENCIES IN RECEIVER MIXERS

OPERATING FREQUENCY 170000.000		CRYSTAL FREQUENCY 16200.000	
CRYSTAL MULTIPLIER 10		IF 8000	
TEST LIMIT 200000.000		MS -12	MF 14

SPURIOUS FREQUENCY MINUS OPERATING FREQUENCY	SPURIOUS RESPONSE FREQUENCY	CRYSTAL HARMONIC	SPURIOUS FREQUENCY HARMONIC
-145800.000	24200.000	1	1
-161800.000	8200.000	1	1
-129600.000	40400.000	2	1
-145600.000	24400.000	2	1
-113400.000	56600.000	3	1
-129400.000	40600.000	3	1
-97200.000	72800.000	4	1
-113200.000	56800.000	4	1
-81000.000	89000.000	5	1
-97000.000	73000.000	5	1
-64800.000	105200.000	6	1
-80800.000	89200.000	6	1
-48600.000	121400.000	7	1
-64600.000	105400.000	7	1
-32400.000	137600.000	8	1
-48400.000	121600.000	8	1
-16200.000	153800.000	9	1
-32200.000	137800.000	9	1
0.000	170000.000	10	1
-16000.000	154000.000	10	1
16200.000	186200.000	11	1
200.000	170200.000	11	1
32400.000	202400.000	12	1
16400.000	186400.000	12	1
48600.000	218600.000	13	1
32600.000	202600.000	13	1
64800.000	234800.000	14	1
48800.000	218800.000	14	1
81000.000	251000.000	15	1
65000.000	235000.000	15	1
97200.000	267200.000	16	1
81200.000	251200.000	16	1
113400.000	283400.000	17	1
97400.000	267400.000	17	1
129600.000	299600.000	18	1
113600.000	283600.000	18	1
145800.000	315800.000	19	1
129800.000	299800.000	19	1
162000.000	332000.000	20	1
146000.000	316000.000	20	1
178200.000	348200.000	21	1
162200.000	332200.000	21	1
194400.000	364400.000	22	1
178400.000	348400.000	22	1
194600.000	364600.000	23	1

FIG. 2 COMPUTER READOUT WITH N = 1 AND WIDE TEST LIMIT

PREDICTION OF SPURIOUS FREQUENCIES IN RECEIVER MIXERS

OPERATING FREQUENCY 170000.000 CRYSTAL FREQUENCY 16200.000
CRYSTAL MULTIPLIER 10 IF 8000
TEST LIMIT 1000.000 MS 0 MF 10

SPURIOUS FREQUENCY MINUS OPERATING FREQUENCY	SPURIOUS RESPONSE FREQUENCY	CRYSTAL HARMONIC	SPURIOUS FREQUENCY HARMONIC
0.000	170000.000	10	1
200.000	170200.000	11	1
66.667	170066.667	31	3
133.333	170133.333	32	3
80.000	170080.000	52	5
120.000	170120.000	53	5
85.714	170085.714	73	7
114.286	170114.286	74	7
-925.000	169075.000	83	8
-900.000	169100.000	84	8
88.889	170088.889	94	9
111.111	170111.111	95	9
-720.000	169280.000	104	10
900.000	170900.000	105	10
-700.000	169300.000	105	10
920.000	170920.000	106	10
90.909	170090.909	115	11
109.091	170109.091	116	11
-583.333	169416.667	125	12
766.667	170766.667	126	12
-566.667	169433.333	126	12
783.333	170783.333	127	12
92.308	170092.308	136	13
107.692	170107.692	137	13
-485.714	169514.286	146	14
671.429	170671.429	147	14
-471.429	169528.571	147	14
685.714	170685.715	148	14
-986.667	169013.333	156	15
93.333	170093.333	157	15
-973.333	169026.667	157	15
106.667	170106.667	158	15
-412.500	169587.500	167	16
600.000	170600.000	168	16
-400.000	169600.000	168	16
612.500	170612.500	169	16

FIG. 3 COMPUTER READOUT WITH N = 16 AND 1 MC TEST LIMIT