The *Lenkurt*®

MAY 1969

DEMODULATOR

overloaded microwave systems — part 1

Complicated voice and data loading requires special equations to calculate actual capacity.

Microwave communication systems, like most systems built for use in a constantly expanding consumer market, seem to reach their maximum capacity before they should. Even when extra capacity has been painstakingly engineered into a system, it is not at all uncommon to find that even this additional capacity has been consumed earlier than anticipated.

As an FM–FDM (microwave-multiplex) system expands to its maximum capacity, problems arise as more circuits or services are required. In general, these systems consist of several microwave hops in tandem between the end points of the system, with spur or sideleg hops often branching from the intermediate points.

When is a System Overloaded?

In complex systems it is possible to have portions of the system operating at or near the overload point while the other portions are carrying much lighter loads. In determining an overload, it is only necessary to consider the single most heavily loaded microwave hop.

In an FM system there are several interrelated factors which limit maximum capacity. An overload exists when one or more of the following limits has been exceeded:

1) All of the available or usable baseband spectrum is in use.
2) The point at which total baseband signal power (system loading) if increased would cause unacceptable performance.
3) System usage is such that any increase in either the top baseband frequency or the system loading would cause emission bandwidth to exceed that legally allowed for the particular frequency band.

In FM systems, the first two of these limits often have some degree of elasticity. The third, however, is a legal limitation which cannot be exceeded without legal violation. Perhaps the best approach is to evaluate the nature of the emission, its limitations, a method by which it can be calculated, and how it is affected by various parameters of the microwave system.

Legal Limitations of Capacity

The allowable maximum bandwidth (necessary or occupied, whichever is greater) for microwave systems under the Industrial Radio Services is established in Paragraph 91.111 of the Federal Communications Commission rules. It is:

8 MHz in the 1850-1990 MHz band
800 kHz in the 2130-2150 and 2180-2200 MHz bands
10 MHz in the 6575-6875 MHz band
20 MHz in the 12,200-12,700 MHz band

Paragraph 2.202 of the FCC rules defines the various emission characteristics and provides formulas for calculating the "necessary bandwidth."

The type of service and the allowable bandwidth for a particular service is formalized in an "emission designator," which includes first the bandwidth in kHz, then a letter indicating the type of modulation (F for frequency modulated systems), then a code number indicating the type of transmission (usually "9" for composite transmission in case of FM systems with FDM multiplex). Thus the emission designators for the bands listed above would be 8000F9, 800F9, 10000F9 and 20000F9 respectively.

The formula given by FCC for calculating the necessary bandwidth of an F9 transmission is:

(A) $B_n = 2M + 2DK$

where:

B_n = *necessary bandwidth in kHz*

M = *maximum modulation frequency in kHz*

D = *peak deviation in kHz, defined as half the difference between the maximum and minimum values of instantaneous frequency.*

K = *a numerical factor depending upon the allowable distortion. A commonly used value for K in such systems is 0.9, though a value of 1.0 is sometimes used.*

The value of M for a particular system is easily established.[1] It is simply the frequency of the top modulating channel applied to the baseband. The value of D, however, is somewhat more elusive since the composite load applied to the baseband is a varying and complex quantity whose peak value can only be described statistically. The value of K is, as stated, very close to 1.0.

The multiplex used, except for systems of very low density, is almost exclusively of the single-sideband suppressed-carrier type (SSBSC).

Studies on operating systems have led to the following equations for calculating the rms (root mean square) value of white noise power, simulating the equivalent busy hour load of a given number of voice channels multiplexed into a baseband by SSBSC techniques (Fig. 1).

(B)

$P = (-15 + 10 \log N)$ dBm0 (N is 240 or more)

or:

(C)

$P = (-1 + 4 \log N)$ dBm0 (N is 60 to 240)

where:

P = *equivalent rms white noise power applied over the same baseband spectrum as occupied by the multiplex channels.*

N = *number of voice channels*

dBm0 = *dB with respect to the power of a single channel test tone at zero relative level.*

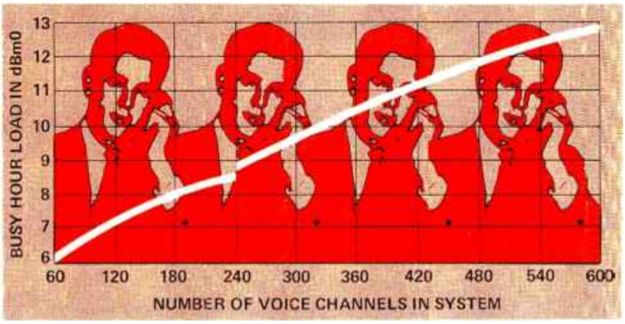
These equations, originated by CCITT and CCIR, are almost universally accepted as a basis for the design and testing of multi-channel microwave systems and provide a basis for calculating peak deviation (Factor D in equation (A)).

Calculating D for Voice Systems

The starting point for the calculation of D (peak deviation) is the

[1] Electronics Industries Association (EIA) has submitted to FCC a proposal that a peak factor of 11.5 dB be used instead of the 13 dB which has been customary, and that a value of 1.0 be used for the factor K for the present. The result of these changes would reduce the calculated values of 2 DK by approximately 8%. This would allow a slight increase in channel capacity for the same necessary bandwidth.
Industry's interpretation is that M should properly be taken as the frequency of the top information-bearing channel in the system, and that a sinusoidal continuity pilot located above the baseband should not be considered to be the "top modulation frequency" and should be excluded from the determination of M.

Figure 1. This graph, based on equations (A) and (B), shows the busy hour load (in dBm0) for the various number of voice channels used in a particular system.



known per-channel rms deviation and the known power of its signal. The per-channel deviation is a basic FM system parameter frequently chosen as 200 kHz rms. The baseband power of the test tone producing this deviation is 0 dBm0 rms.

The parenthetical expressions in (B) and (C), called the "noise loading ratio", express the dB ratio between the rms power of a white noise load whose peaks are equal to the peak values of the complex baseband signal during the busy hour, and the rms power of a test tone.

The peak value of white noise power is a statistical parameter with no specific value, but is commonly taken as 13 dB above the rms power. The use of two different equations for calculating the white noise load equivalent reflects the fact that the peak to rms factor of the complex signal from a number of voice channels is relatively constant at 13 dB for systems with more than 200 channels, but is variable and somewhat higher for systems with fewer channels (Fig. 2).

Deviation in an FM system has the dimension of voltage. Consequently, the effect of changes in deviation can be calculated as a 20 log function of changes in load power.

The following equations can be used to calculate the peak deviation for a multichannel SSBSC voice system:

(D)

$$D = 4.47d\left(\log^{-1}\frac{-15 + 10\log N}{20}\right)$$

(N is 240 or more)

(E)

$$D = 4.47d\left(\log^{-1}\frac{-1 + 4\log N}{20}\right)$$

(N is 60 to 240)

where:

D = *peak deviation in kHz*

d = *per-channel test tone deviation in kHz, rms*

N = *number of SSBSC voice channels in system*

$$\text{Peak factor} = \log^{-1}\frac{13}{20} = 4.47$$

Example A:

A 300 channel radio system could typically have a 200 kHz per channel rms deviation.

$$\begin{aligned} D &= (4.47)(200)\left(\log^{-1}\frac{9.77}{20}\right) \\ &= (4.47)(200)(\log^{-1} .4885) \\ &= (4.47)(200)(3.08) \\ &= 2753 \text{ kHz} \end{aligned}$$

Equation (A) can be used to calculate B_n, noting that M = 1300 kHz (top channel of a 300 kHz system) and taking 0.9 for K. B_n = 2 x 1300 + 2 x 2753 x 0.9 = 7555 kHz

For standard SSBSC multiplex configurations of 120 channels to about

960 channels, the frequency of the top channel in an N-channel system can be very closely approximated as (4.13 N + 60) kHz. By using this approximation for M, taking K as 0.9, and substituting the appropriate values of D from (D) and (E) respectively, the following equations for B_n in terms of N and d can be derived. (It should be emphasized that they apply only to systems used primarily for voice):

(F)

$$B_n = 120 + 8.26N + 1.43d\,N^{0.5}$$

(N is 240 or more)

(G)

$$B_n = 120 + 8.26N + 7.17d\,N^{0.2}$$

(N is 120 to 240)

These equations provide insight into the complicated way the necessary bandwidth varies as a function of the number of channels and per channel deviation in voice operation.

The equations permit calculation of any one of the three variables (B_n, N, and d) provided the other two are known, and can be used to determine what combinations of number of channels and per channel deviation can be used without exceeding a specific value of B_n.

Example B:

A typical microwave system in the 6 GHz industrial band has the limitation of 10000F9 emission. (From Example A, it is clear that there will be no problem with a 300 channel system using 200 kHz per channel deviation.)

But suppose 600 channels are desired in the same bandwidth.

What per channel deviation will allow staying within 10000F9?

By substituting 1000 for B_n and 600 for N in (F) it can be easily calculated that the deviation must be reduced to 140 kHz.

If d is left at 200 kHz per channel, it can be shown that N cannot exceed about 450 channels if B_n is not to exceed 10000 kHz.

Thus seven complete supergroups, or 420 channels, can be accommodated on a system using 200 kHz per channel deviation, within the 10000 kHz bandwidth limitation, but eight supergroups create an overload.

Calculating Voice and Data

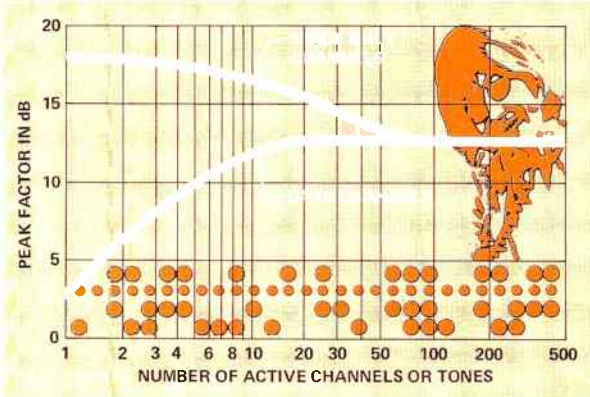
Present day systems have a significant percentage of the derived SSBSC channels devoted to the transmission of systems of submultiplexed tones carrying data or telegraph. The number of tones of this type in an SSBSC channel can vary from one to 25 or more. Their power represents a relatively constant rms load to the baseband, since the tones are on continuously. When the total number of individual data signals on the system exceeds about 15, the peak to rms factor for their complex summation approaches that of white noise.

If the levels chosen for each data or telegraph circuit are such that the total rms power of their tones submultiplexed in any SSBSC channel is 15 dBm0, the data loading per SSBSC channel will be the same as if it had been used for voice. In this case these equations can be used to calculate deviation and bandwidth.

The common practice of putting data at a somewhat higher level means the loading due to the number of channels devoted to data will be much greater than if they had been devoted to voice. This also means greater overall loading and deviation.

The necessary calculations for a mixture of voice and data channels are simple in theory. They can become complicated in practice, however, because there are so many possible combinations of voice and non-voice circuits. The following equation is a generalized form of (D) and (E):

Figure 2. The patterns for the two peak factors – peak to rms ratios – of data and voice are essentially the same when the number of channels is large. However, restriction of data to low levels will affect the signal-to-noise ratios.



(H)

$$D = 4.47\, d\left(\log^{-1} \frac{NLR_{tot}}{20}\right) kHz$$

which leads to a generalized form of (F) and (G):

(I)

$$B_n = 120 + 8.26\, N + 8.05d \cdot \left(\log^{-1} \frac{NLR_{tot}}{20}\right)$$

where:

D, d, B_n, and N are all as before and NLR_{tot} is the Noise Loading Ratio corresponding to the total equivalent voice channel power plus the equivalent power of all non-voice groups.
(Note: N is the total number of SSBSC channels in the system, regardless of use. The function of N is only to establish the top modulating frequency M).

Before (H) and (I) can be used, a preliminary calculation must be made to determine the value of NLR_{tot}. The simplest way is to calculate separately the dBm0 equivalent noise power of the channels used for voice (using (B) or (C)), the equivalent dBm0 noise power of each non-voice group and then on a power summation basis, combine all the powers to obtain the equivalent total baseband load of white noise power. The NLR_{tot} in dB is then numerically equal to the dBm0 value of the equivalent white noise load. Once NLR_{tot} has been calculated, it can be used in (I) to obtain B_n, or with (H) and then (A) to determine both D and B_n.

The following example will illustrate the method.

Example C:

A 6 GHz system with 300 SSBSC channels, of which 200 channels are used for voice transmission, 40 channels are used for data at a power of –10 dBm0 per SSBSC channel, and 60 channels are used to carry submultiplex telegraph tones, each tone at a power level of –21 dBm0 and with each of the 60 SSBSC channels carrying 20 such tones. The per channel rms test tone deviation is 200 kHz. To calculate necessary bandwidth:

1. Calculate noise load power corresponding to 200 voice channels, using (C), as (–1 +4 log 200) = +8.2 dBm0.
2. Calculate noise power corresponding to 40 data channels at –10 dBm0 per channel as (–10 + 10 log 40) = +6.02 dBm0.
3. Calculate noise power corresponding to 20 tones in one SSBSC

channel as (–21 +10 log 20) = –8 dBm0 and the noise power corresponding to 60 such SSBSC channels as (–8 + 10 log 60) = m + 9.78 dBm0.

4. Sum the three noise powers, +8.2 dBm0, +6.02 dBm0, and +9.78 dBm0 on a power basis, by using appropriate curves or by converting each value to its equivalent in milliwatts, adding, and reconverting to dBm0. The power sum will be found to be very close to +13 dBm0 or about 3.2 dB higher than the equivalent noise loading of 300 voice channels.
5. As indicated above, the NLR corresponding to +13 dBm0 of noise power is 13 dB. Substitute this value for NLR_{tot} in (H), which gives the following:

$$\begin{aligned} D &= 4.47 \times 200 \times \left(\log^{-1} \frac{13}{20}\right) \\ &= 4.47 \times 200 \times 4.47 \\ &= 4000 \text{ kHz} \end{aligned}$$

(It is coincidental that the noise loading factor equals the peak factor. Generally, they will be different.)

6. With D known, use (A) to calculate the "necessary bandwidth". The value of M is still 1300 kHz, corresponding to the frequency of the top channel of a 300 channel SSBSC system, and the 0.9 value is still appropriate for K. This gives:

$$\begin{aligned} B_n &= 2 \times 1300 + 2 \times 4000 \times 0.9 \\ &= 9800 \text{ kHz} \end{aligned}$$

or:

Equation (1) could have been used to calculate B_n directly.

The methods used in Example C can be extended to cover other situations provided the basic principles are followed.

To avoid possible confusion, these calculations of peak deviation are based on systems which do not have emphasis and whose per-channel test tone deviations have the same value regardless of the position of the channel in the baseband. When emphasis and deemphasis networks are used, per channel test tone deviation is not a constant but is a function of channel baseband frequency. Higher channels deviate more than lower channels, but systems are generally so arranged that the total deviation remains the same and the equations are still valid.

Capacity Limitations

Microwave equipments are generally designed with some specific maximum capacity in mind, usually in some multiple of the standard 60-channel supergroup. In older systems, and in light route or spur legs, 120 channel and 240 channel systems were often used. Present usage tends toward systems with 300 channel capacity, even higher for backbone routes.

Selecting the proper equipment and employing the most effective field application necessarily requires some specific criterion of channel noise performance. Noise performance is an intricate function of the number of channels, the per channel deviation, the presence or absence of emphasis networks, the per channel loading, the receiver noise figure, the RF signal level, the fade margin needed to give the desired reliability, and the i-f bandwidth – to mention a few. There are many trade-offs and balances involved. The choices made when engineering a system for 300 channels would not be the same as those for 600 channels.

LENKURT ELECTRIC CO., INC.
SAN CARLOS, CALIFORNIA 94070

Bulk Rate
U.S. Postage
Paid
San Carlos, Calif.
Permit No. 37

RETURN REQUESTED

[illegible]
[illegible]
[illegible]
[illegible], ILL. 61074

Lenkurt Offices

San Carlos
Stamford, Conn.
Falls Church, Va.
Chicago
Atlanta
Dallas

The Lenkurt Demodulator is circulated monthly to technicians, engineers and managers employed by companies or government agencies who use and operate communications systems, and to educational institutions. Permission to reprint granted on request.

LITHO IN USA