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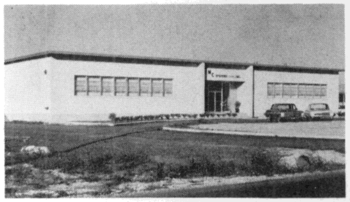
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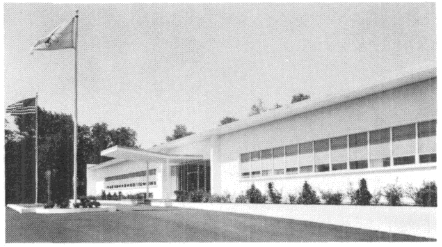
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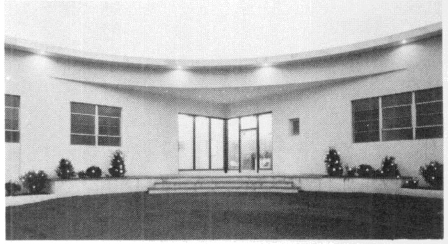
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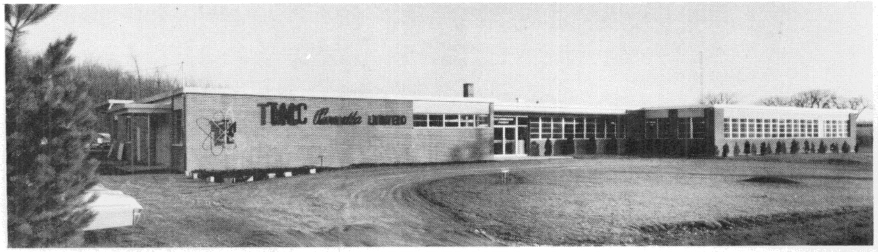
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A paper, delivered by

D. V. CARROLL, MBE, CD,
M. E. I. C., Sen. Mem. IRE
President and Managing Director

TMC *Canada* LIMITED

OTTAWA.

to

The QUEBEC Section of the Institute

of

ELECTRICAL and ELECTRONIC ENGINEERS

describing

the advantages of Single Sideband communications over convential Amplitude Modulation communications and a simplified theoretical discussion of the techniques involved.

February 1960
Revised September 1961
2nd Printing February 1962
3rd Printing February 1963

PREFACE:

Although general acceptance of Single Sideband communications techniques was initially slow, the tremendous advances in this branch of the electronics art during the last few years, has resulted in wide-spread employment of SSB., by most military and commercial agencies where the necessity for reliable communications circuits is paramount. The increase in use of SSB in radio amateur circles is most evident in the steady climb of equipment sales graphs and the regular addition of SSB "ham" stations on the air.

Domestic and International radio regulations are being tightened to require technical performance and operation of radio equipment to reduce interference between stations and also to ensure at the same time, greater use of the available H/F frequency spectrum. These objectives are, in fact, achievable only by employment of SSB, with its many advantages concurrent with the present state of the art. As a result of its growing use and popularity, we in the electronics industry, find ourselves more frequently called upon to explain the differences between SSB and the so-called "Conventional AM" practices.

It is the objective of this lecture, to assist in the enlightment of such "Seekers after truth" and I shall attempt to explain in some brief detail, not only how the theoretical advantages of SSB are achieved, but also to offer at least one practical example showing proof of SSB superiority, as compared to conventional systems under operating conditions.

Much has been written on Single Sideband techniques, and there is no shortage of technical references and material on this subject. My lecture therefore will not expose you to any startling new principles which have not previously been covered in the numerous excellent text-books and papers written on this subject. It is designed, however, to simplify and gather together in a nut-shell, as-it-were, the basic principles from the literature in such a form as to present a talk that will introduce the subject to you who are busy on other more important electronic and management problems, as well as to present the SSB picture in what I hope is a clear and concise form to those students who are being exposed to it for the first time.

Thus to some of you I shall be covering old ground. However, a general recapitulation may serve as a refresher to the more knowledgeable and assist those with less knowledge in gaining an understanding of the reasons for the superiority of Single Sideband communications under poor propagation conditions - WHEN A COMMUNICATOR NEEDS DEPENDABLE COMMUNICATIONS MOST!

SINGLE SIDE-BAND

HISTORY:

When we speak of Single Side-band, we really mean, to give it its full title, Single Side-band Suppressed Carrier, where only the intelligence in the side-band is that part of the signal used, everything else being suppressed. This form of communication has come into popular usage in the past ten or twelve years due, in the main, to the ever-increasing demands on the high frequency spectrum for more and more channels, as the SSB signal occupies considerably less spectrum space. SSB has many other advantages which we will attempt to show in the course of this lecture.

Although SSB as we mentioned, has come into popular usage in the past decade, it was shown as early as 1914 that when two frequencies, one a carrier frequency and the other an audio modulation, were heterodyned, two new frequencies were produced, the upper and lower sidebands, and the existence of the carrier and the sidebands as separate entities was proven during tests at the Naval Radio Station in Arlington Va., (NAA) in 1915. In fact, H. P. Arnold tuned his transmitter antenna to resonate only at the lower sideband frequency thereby attenuating the carrier and upper sideband, and SSB was born. Later, Mr. John R. Carson of the American Telephone and Telegraph Company, conducted further tests and reached the very important mathematical conclusions that afford the basis for SSB as we know it today:-

i) That both of the sidebands contain identical information, and in fact were mirror images of each other,

and

ii) That, of the intelligence radiated by the antenna, the greatest amount of power was contained in the carrier.

Mr. Carson further went on to prove that the carrier contained absolutely no useful information other than as a reference for the side-bands. He then developed an electronic circuit called a "Balanced Modulator" which cancelled out the carrier and left the sidebands intact. He took out patents on this system as early as 1923. Using this method, the A. T. & T., established a trans-Atlantic submarine cable in 1927, taking advantage of the power and spectrum space saving afforded by Mr. Carson's invention. Today this technique is used wherever high efficiency space saving radiated transmission is needed and telephone companies use sideband to carry many conversations on each side of the suppressed carrier frequency.

In order to explain SSB and its advantages over amplitude modulation, let us take a look at the amplitude modulated signal:-

Diagram (1) shows the normal C.W. (Carrier) frequency. Now impose on this carrier an audio tone Sine-wave modulation and you will see the usual modulated envelope (Diagram (2)), the carrier being modulated by this tone.

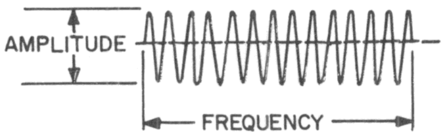


DIAGRAM I.

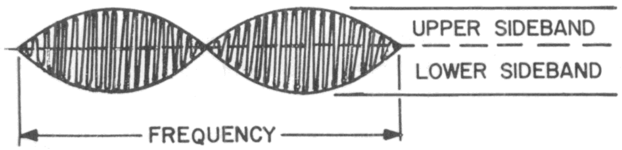
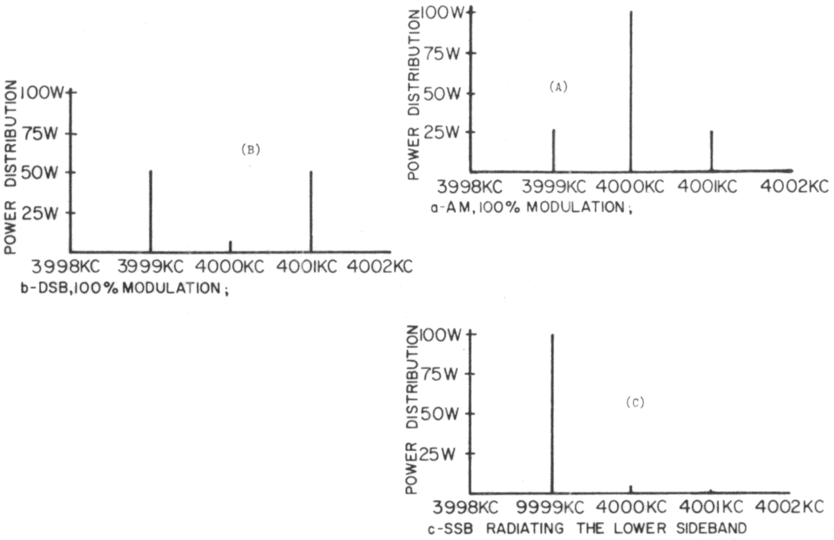


DIAGRAM 2.

It will be seen that for a full 100% modulation, 50% of the power is developed in producing the envelope, so that if, for argument's sake, we use a 100 watt transmitter to produce this envelope, such a transmitter will actually be producing 150 watts of R.F. power with 50 watts being used in the sidebands and 100 watts being required to produce the carrier. This is shown graphically in diagram (3A):-



a-AM,100% MODULATION;

b-DSB,100% MODULATION;

c-SSB RADIATING THE LOWER SIDEBAND

DIAGRAM 3

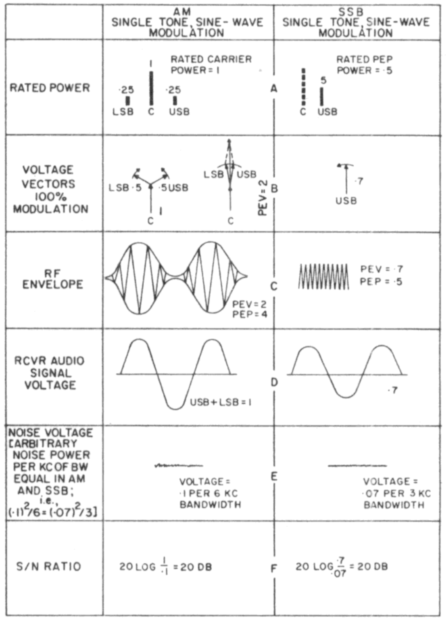
Looking at diagram (3A) you will notice it depicts a vector showing the rated carrier power of 100 watts and on either side of it, spaced in the frequency spectrum according to the frequency of the modulation used, we have the two sidebands, the lower sidebands and the upper sideband, each having 25 watts of power. Now, looking back at the modulation envelope (Diagram (2)), you will see that the intelligence on the upper sideband, is identical with the intelligence on the lower sideband, displaced by 180 degrees, and is, in fact, the mirror image of it. Important to remember, is that either one of these sidebands, upper or lower, carries the same intelligence and either one of them is sufficient to produce, in a radio receiver under the right conditions, all the intelligence that is necessary for communications.

If this is the case, then you can see from the diagram that, in order to produce 25 watts of intelligence power, we really have to use a system capable of handling 150 watts.

Now supposing we were to remove the carrier completely. With the same input power available, you would now find that the distribution contained in the sidebands would be 50 watts in each sideband. See Diagram 3B. So that by the mere removal of the carrier itself, even using both sidebands, we have increased the talk or intelligence power of our transmitting system by a factor of two, i.e. 3db. This is exactly what happens, assuming that both power sources are the same in either case. Now, as we have shown that both sidebands contain the same identical intelligence, it is really quite unnecessary to use them both if one will do, so let us remove one of the sidebands and you now have immediately doubled the power in the remaining sideband. See Diagram 3C. In other words we have 100 watts full rated power contained in the intelligence of the sideband we are using and we have increased our talk or intelligence power over the amplitude modulated condition, four times, or 6db, a very important advantage you will no doubt agree.

RELATIVE ADVANTAGES OF SSB/AM AS COMPARED TO RECEIVER S/N RATIO.

One of the most straightforward manners in which to evaluate the relative advantages of AM systems and SSB systems, is to determine the transmitting power necessary to produce a given signal-to-noise ratio at the receiver for the two systems. This is considered a fair comparison as it is the S/N ratio which determines the intelligibility of the received signal. Diagram (4) shows such a comparison, where 100% signal tone modulation is assumed. Fig A in this diagram shows the power spectrum for an AM transmitter rated at one unit of carrier power with 100% Sine wave modulation. Such a transmitter actually produces one and one-half units of R.F., power; $\frac{1}{4}$ unit of power in each of the two sidebands and one unit in the carrier. This transmitter is compared with a Single Sideband transmitter rated at $\frac{1}{2}$ unit of Peak Envelope Power (Peak Envelope Power being defined as the RMS power developed at the crest of the modulation envelope). These graphs show that an SSB transmitter rated at $\frac{1}{2}$ unit of Peak Envelope Power (PEP), will produce the same S/N ratio in the output of the receiver as the AM transmitter rated at one unit of carrier power. Fig B in this diagram indicates the voltage vectors related to the power spectrum. The AM voltage vectors show the upper and lower sideband voltages of $\frac{1}{2}$ unit, rotating in opposite directions around the carrier voltage of one unit. For AM modulation, the resultant of the two sideband voltage vectors must either be directly in phase or directly out of phase with the carrier and the resultant shown when the upper and lower sideband voltages are instantaneously in phase, produces a peak envelope voltage equal to twice the carrier voltage with 100% modulation. The $\frac{1}{2}$ unit of voltage shown in each vector, produces the $\frac{1}{4}$ unit of power shown in Fig. A, power being proportional to the square of the voltage. In the SSB case, the signal vector of .7 unit of voltage at the upper sideband frequency, produces the $\frac{1}{2}$ unit of power shown in Fig. A. In Fig. C, of this diagram, is shown the RF envelopes developed by the voltage vectors. That of the AM signal is shown to have a Peak Envelope Voltage (PEV) of two units, the sum of the two sideband voltages plus the carrier voltage. This results in a Peak Envelope Power of four units of power. In the case of SSB, the Peak Envelope Voltage is .7 units of voltage for a resultant Peak Envelope Power of $\frac{1}{2}$ unit of power. Fig, D, in this diagram shows the respective demodulated signals in both cases. In the case of AM, an audio voltage develops which is equivalent to the sum of the upper and the lower sideband voltages in this instance, one unit of voltage. In the case of the SSB receiver, an audio voltage of .7 units develops, which is equivalent to the transmitter upper sideband signal.



SSB AND AM. COMPARISON WITH EQUAL SIGNAL-TO-NOISE RATIO

DIAGRAM 4

If an arbitrary broadband noise level of .1 unit of voltage is chosen for the 6kc/s bandwidth of the AM receiver, then the same noise level is equal to .07 unit of voltage for the 3kc/s bandwidth of the SSB signal, and this is shown in Fig. E, of the diagram. These values represent the same noise power level per Kc/s of bandwidth:-

$$\text{i.e.} \quad \frac{.1^2}{6} = \frac{.07^2}{3}$$

With this chosen noise level, the S/N ratio in the AM system is 20 log S/N in terms of voltage, or 20db and the S/N ratio of the SSB system is also 20db, the same as for the amplitude modulated system. Therefore the $\frac{1}{2}$ power unit of rated Peak Envelope Power for the SSB transmitter produces the same signal intelligibility as the one power unit rated carrier power for the AM signal. This conclusion can be re-stated as follows:-

Under ideal propagation conditions but in the presence of broadband noise, the SSB and AM systems perform equally if the total sideband power of the two transmitters is equal.

This means that the SSB transmitter will perform as well as an AM transmitter, with TWICE the carrier power rating, under ideal propagation conditions.

It is a basic fact that the more selective the receiver, the better the S/N ratio, and due to the 3Kc/s bandwidth required for SSB as opposed to 6Kc/s for AM., it can be said that an additional 3db gain in the reception of SSB is achieved, thus making the total gain of power increase over AM, of 9db. There is a considerable difference of opinion as to whether or not this last 3db gain exists, especially in the presence of impulse-type noise, so that this is subject to debate. How much of the total 9db gain is actually realized in operation depends entirely on the frequency spectrum band conditions. Under ideal conditions, there is little difference in AM or SSB signals, but as the propagation conditions deteriorate, SSB has an increasing advantage over AM signals. This is adequately displayed in the graph depicted in Diagram (5). In this presentation you will see the "Intelligibility" in decibels plotted on the "Y" axis against varying propagation conditions on the "X" axis. Taking zero db as a reference point, it will be seen that either the AM or SSB transmitter with equal sideband power, will perform equally well for ideal conditions. Under somewhat less than ideal conditions, termed "Good" in the graph, you will see that the SSB transmitter has a gain of 3db over the AM transmitter, a gain of 6db for poor conditions and approximately 9db under severe fading and interference.

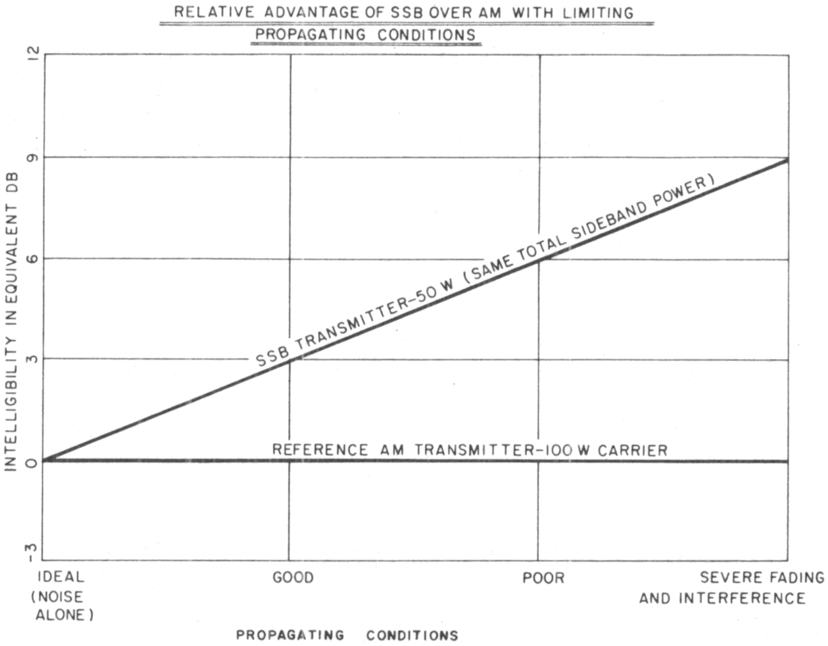
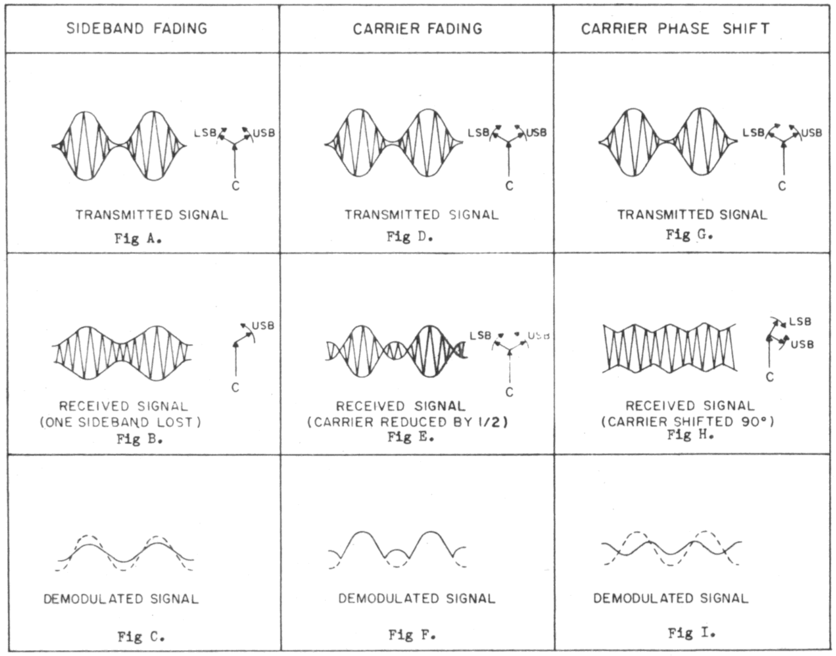


DIAGRAM 5

SSB ADVANTAGES DURING SELECTIVE FADING CONDITIONS.

Single Sideband transmission and reception has another distinct advantage over AM, under selective fading conditions. With long distance H/F transmissions (Sky wave), AM transmission is subject to selective fading, producing severe distortion in many instances and often a weak signal due to fading that is quite unintelligible. The AM transmission is subject to deterioration under these poor propagation conditions because all three components of the transmitted signal, the upper sideband, the lower sideband and the carrier, must be received exactly as transmitted to realize fidelity and the theoretical power from the signal. Diagram (6) depicts this deterioration of the AM signal under different types of selective fading. In the case of sideband fading, the loss of one of the two transmitted sidebands, results only in a loss of signal voltage from the demodulator, with some slight distortion. This distortion is not basically detrimental to the signal as the ONE SIDEBAND CONTAINS THE SAME INTELLIGENCE AS THE OTHER. However, as the receiver is operated on a broad bandwidth, the noise level remains constant even though only one sideband is received and this is equivalent to a 6db deterioration in the S/N ratio out of the receiver. Looking at Diagram (6), we see in Fig A, the original transmitted signal for AM conditions, in Fig B, the form of the received signal when one side band is lost and in Fig C, the resultant demodulated signal.



DETERIORATION OF AN AM.SIGNAL WITH SELECTIVE FADING

DIAGRAM 6

The most serious result of selective fading to an AM signal, and incidentally, the most common occurs when the carrier level is attenuated more than the sidebands. Under these conditions, the carrier voltage at the receiver is less than the sum of the two sideband voltages and the RF envelope does not retain its original shape, with resultant extreme distortion upon demodulation, in fact over-modulation. This condition is depicted in Figs D, E and F, of the diagram under the Carrier Fading, heading.

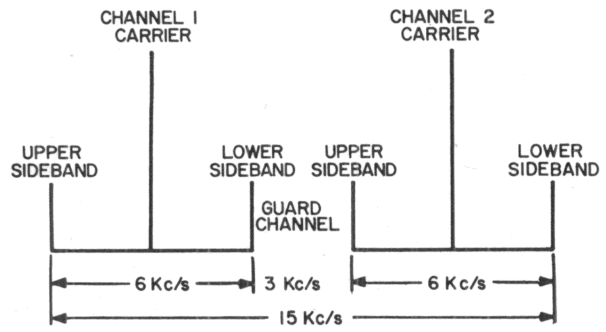
In the category of "Selective fading" there is also a shifting between the relative phase position of the carrier and the sidebands and, as shown in the diagram Figs G and H, the AM signal is vectorially represented by two counter-rotating sideband vectors which rotate with respect to the carrier vector. The resultant of the sideband vectors is always directly in-phase or directly out-of-phase with the carrier vector. In extreme cases the carrier may be shifted 90° from its original position (Fig. H) and, of course, when this occurs, the resultant of the sideband vectors is ± 90° out of phase with the carrier vector. This has the effect of converting the original AM signal to a phase-modulated signal and the envelope bears no resemblance to the original. Consequently the conventional detector will not produce an intelligible signal.

In single sideband, the signal is not subject to deterioration due to selective fading. Since only one sideband is transmitted, the received signal level does not depend upon the resultant amplitude of the two sideband signals as it does in AM. Since this is so, no distortion can result, or loss of carrier power, or phase shift. Selective fading within the one sideband of the SSB only changes the amplitude and the frequency response of the signal. It rarely produces enough distortion to cause the received signal or voice to be unintelligible.

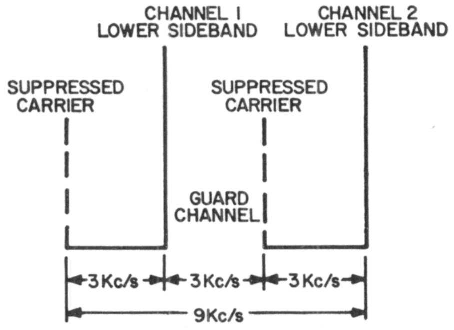
FREQUENCY SPACE CONSERVATION

Another very important advantage of SSB is the conservation and greater utilization of the frequency spectrum. It has been established that intelligent voice frequencies can be contained in the audio frequency ranges from 300 to 3000 cycles. Taking this premise, you can see that in the AM condition a total bandwidth of 6Kc/s is required, 3kc/s for the upper sideband and 3kc/s for the lower sideband.

Now if a guard channel of 3 kc/s is used, the next AM station taking up a further 6kc/s, means that the two AM channels require a total frequency spectrum space of 15 kc/s. (See Diagram (7)). In the case of SSB, two voice channels can be contained in a frequency spectrum space of only 9 kc/s, which includes a guard channel of 3 kc/s., as depicted in Diagram 7. Further by judicious choice of locations and non-interfering antenna, two SSB stations could be operated on the same frequency, one using lower sideband and the other using upper sideband, thereby more than doubling the channel capacity of the already overcrowded high frequency spectrum. This close spacing of frequency



(a) 2 CHANNELS OF AM IN 15 Kc/s BANDWIDTH USING 3 Kc/s GUARD CHANNEL.



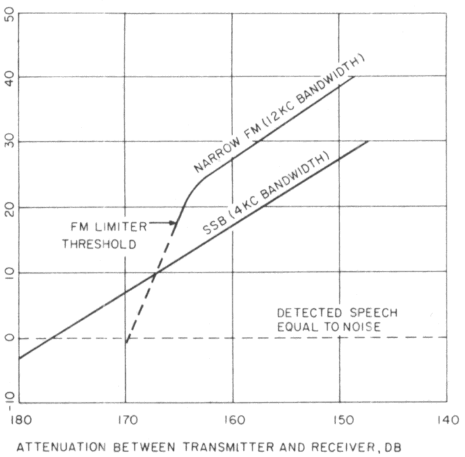
(b) 2 CHANNELS OF SSB IN 9 Kc/s BANDWIDTH USING 3 Kc/s GUARD CHANNEL.

DIAGRAM 7.

allocations for SSB is within practical limitations due to the fact that only one sideband is being used and more important, we have removed the carrier from the spectrum. The carrier in itself is a source of trouble creating interference due to the heterodyning principle where two carriers adjacent to one another often create audible interference in the demodulating stages of the receiver. Once this carrier is removed, as in SSB, this annoyance is no longer present.

COMPARISON OF SSB WITH FM.

We must note that most of the experimental work carried out to evaluate the performance of SSB systems, has been in its comparison to AM signals. For the record, it must be stated that some work has been done to evaluate its performance with FM systems also, and Diagram (8) shows the predicted results in one such study of an FM system as measured against a comparable SSB system. In this diagram the S/N ratio in decibels is shown against the attenuation between the transmitter and receiver also in decibels. This graph shows that between 150 and 160 db of attenuation between the transmitter and the receiver, i.e. a strong signal, the narrow-band FM system provides a better S/N ratio than the SSB system. However, on a weaker signal, attenuation from 168db onwards, the S/N ratio of the SSB system is better. The conclusions are, that for strong signals the FM system will be better; but this is not an important advantage because when the S/N level is high, a still better S/N ratio will not improve intelligibility. For weaker signals however, SSB will provide an intelligible signal where the FM will not. However, the most important advantage for SSB over FM is that it conserves spectrum space by a factor of 3, as compared to the narrow-band FM:- 4 kc/s versus 12 kc/s in the instance shown on the diagram. An even further saving in spectrum space would be achieved if a 3 kc/s SSB system was used.



SSB PERFORMANCE COMPARED WITH FM

DIAGRAM 8

GENERATION OF SINGLE SIDEBAND SIGNALS

The SSB signal is an audio signal converted to a radio frequency. To facilitate the illustration of this conversion, we use pure sine-wave tones rather than the complex wave-form of the human voice. The heart of the SSB generator is a balanced modulator. The balanced modulator is used whether the signal is produced by either of the two common methods of SSB generation:-

i) Phase method or
ii) Filter method.

Before proceeding, it would be well to consider the operation of this balanced modulator. Diagram (9) shows the circuitry of a basic push-pull balanced modulator and it can be considered as an electronic switch where the carrier frequency is switched on and off at the rate of the modulating signal.

Looking at the push-pull balanced modulator, it would appear to be a simple push-pull amplifier, but this is not the case. For example, assume that the modulating frequency f_m is 3000 cycles and the carrier f_c is 1000 kc/s., and the push-pull tank circuit in the plate is tuned to a frequency of 1000 kc/s. The following condition will then exist:- With no modulation signal present and the two halves of the push-pull circuit perfectly balanced, there will be no carrier output signal. A carrier voltage f_c is applied to the center-tap of the grid transformer and this drives the two grids in parallel. If both grids swing positive simultaneously, the plate currents of the two tubes will increase simultaneously. The effect in the tank circuit is that both pulses of plate current cancel each other out, resulting in zero output. Now consider the case where only the modulation frequency f_m is turned on. The audio signal is applied to the grids in push-pull connection causing the plate currents to vary in the normal push-pull operation. Thus the plate current pulses feed the tank circuit as in a conventional push-pull amplifier. However the plate tank circuit is tuned to 1000 kc/s, not 3000 cycles, and therefore does not present any load impedance to the audio frequencies and the plate current returns to the positive H.T. supply causing no signal voltage to appear at the output. You can see that by careful balancing it has been possible to eliminate the carrier signal in the output circuit and by the proper choice of tuned circuits in the plate load, it is possible to prevent the modulated signal from operating at the output. Therefore when either signal is present in the stage by itself there is no output voltage.

THE BASIC PUSH-PULL BALANCED MODULATOR CIRCUIT

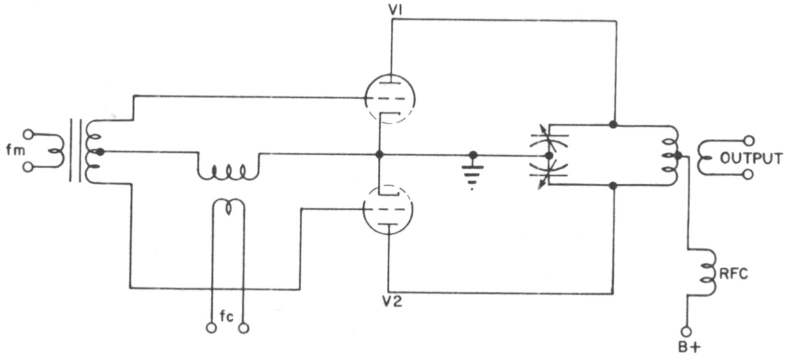


DIAGRAM 9

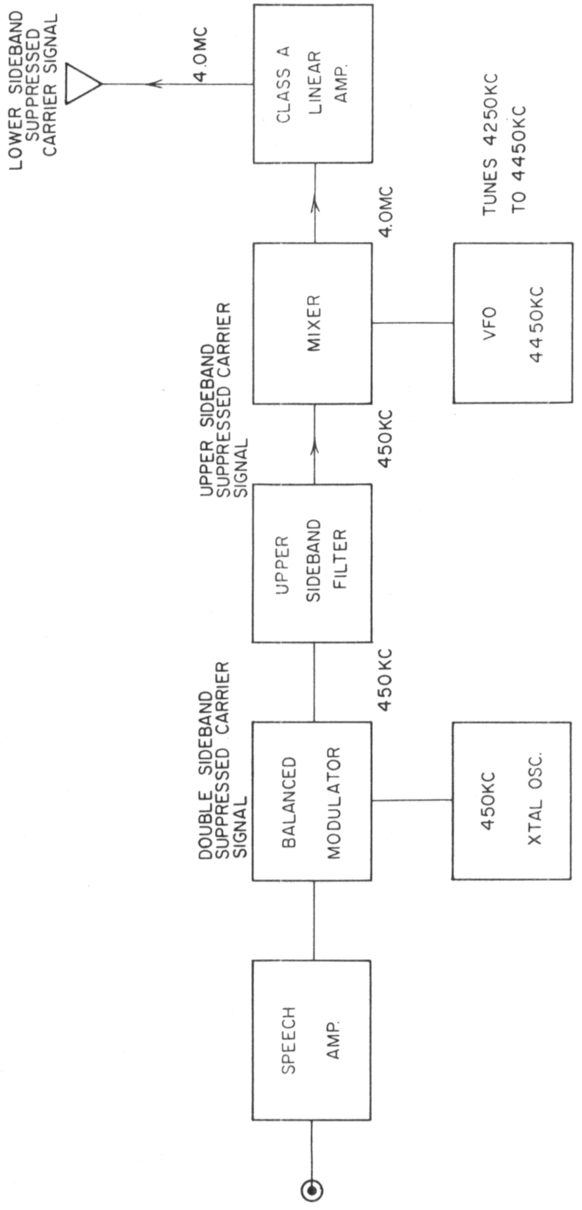
The condition changes when both signals are applied at the same time. The carrier f_c again feeds the grids in parallel but the push-pull feed of the modulation causes one of the grids to swing less positive than the other. This amount is equal to the instantaneous peak voltage of the audio modulation voltage. The stage is no longer perfectly balanced and the signal voltage appears across the 1000 kc/s tuned circuit and if this signal is observed on a spectrum analyzer, it can be seen that it is comprised of frequencies grouped on either side of the carrier frequency and that no carrier frequency is present. Thus a new signal whose frequencies are equal to the carrier frequency plus and minus the modulating frequency, has been generated. In other words, we have created two sidebands, one each side of the 1000 kc/s carrier. This is known as a double sideband suppressed carrier signal and the balanced modulator is acting as a switching tube turning the carrier on and off at a rate determined by the modulating frequency.

It should be especially noted that the generation of undesirable products occur in any mixing operation, as well as the generation of the desired products, and the equipment must be designed to minimize and attenuate these undesirable products. It should also be noted that the carrier frequency injected into the balanced modulator is only theoretically cancelled from the output and in practice, does not determine the extent to which the carrier can be balanced out. With present-day techniques it is possible to obtain carrier suppression of from 30db to 50db below the Peak Envelope Power of the sidebands. However, further suppression by the use of filters, can result in an additional 10 to 15db carrier suppression so that in a properly designed modern-day SSB transmitting system, total carrier suppression of up to 60db plus can reasonably be expected.

A SINGLE SIDEBAND EXCITER:

Diagram (10) shows in block diagram form, a simple filter type SSB exciter. The audio signal, as explained previously, is passed through the balanced modulator and we wind up with two sidebands, an upper and lower, completely divorced from the carrier. In filter type exciters, the SSB signals are normally developed at a low frequency and in order for the system to come up to operating frequency there may have to be several translations. In describing diagram (10) the audio tone is passed from the speech amplifier through the balanced modulator with an I.F. injected frequency of 450 kc/s as the carrier frequency, therefore, coming out of the balanced modulator we have a double sideband suppressed carrier signal that in the case of a 3000 cycle audio tone is 450 kc/s plus and minus 3000 cycles. We now pass this double sideband signal through a highly selective filter with, say, a 450 - 453 kc/s pass-band, and the upper sideband signal only is allowed through, while the lower sideband is attenuated. Conversly, if we only wanted the lower sideband, the highly selective filter would be tuned for a 447 - 450 kc/s band-pass condition, thus passing the lower sideband and attenuating the upper sideband. Two such filters could be used, one for the upper sideband and one for the lower sideband, switching as required.

Remember, the sideband signal in the case of a single tone is a pure sine-wave displaced in the spectrum from its original audio frequency by an amount equal to the carrier frequency, in this case, 450 kc/s. This SSB signal can be demodulated at the receiver only by converting it back down in the frequency spectrum. Now, referring back to Diagram 10, you will note that we have generated through the filter, an upper sideband suppressed carrier signal. It is now possible to place this sideband in any portion of the frequency spectrum that we wish by simply passing it through a mixer, or a succession of mixers, and beating a frequency against it to give a resultant R.F. signal in the frequency spectrum in which we wish to radiate. It is shown in this block diagram that a fre-

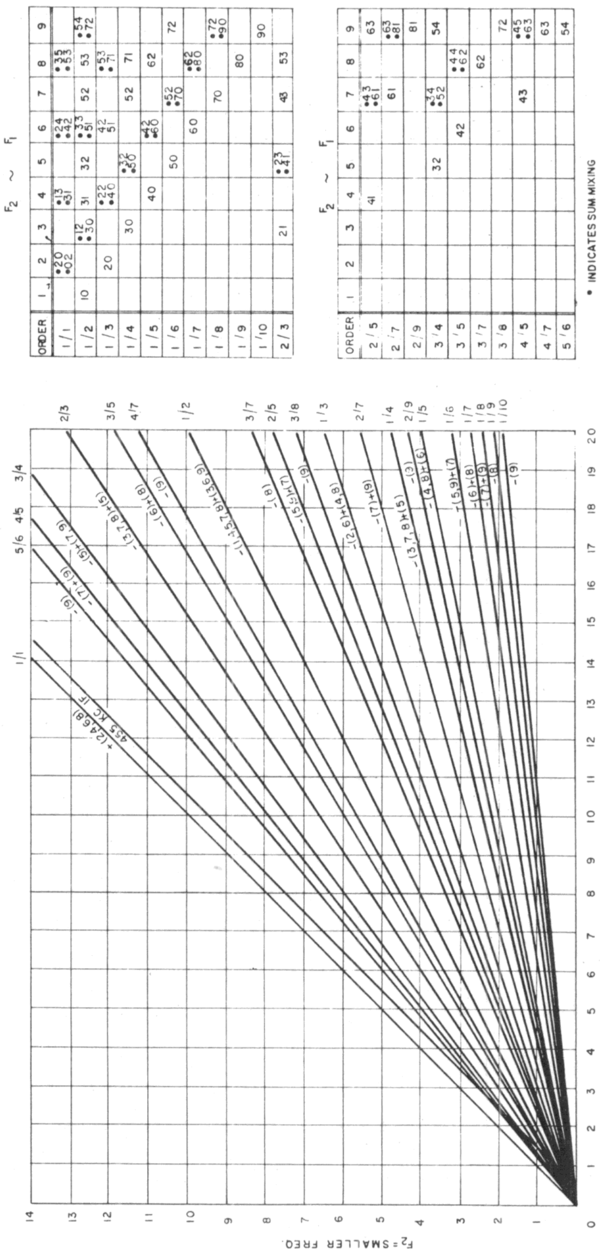


BLOCK DIAGRAM OF A SIMPLE FILTER TYPE SSB EXCITER

DIAGRAM 10

quency of 4450 kc/s has been chosen with a resultant suppressed carrier signal of 4 Mc/s, thus the actual output signal is a lower sideband signal which has been produced from an original upper sideband signal. This is called "Frequency inversion" and does occur at times due to the choice of mixing frequencies used. (For a less complex understanding of the transmission of SSB signals, the simplified system may be examined in reverse in which case it will somewhat resemble the operation of an heterodyne receiver).

As you are probably aware, in the mixing or translation process, one must be very careful in the choice of frequencies used, as this process, while performing its function in generating the sideband signal, also develops other spurious and undesired frequencies and as the final amplifier of the transmitter is normally working under Class A conditions, it will pass many of these undesired frequencies to the radiating system. It is therefore most important to keep these undesired frequencies at a minimum. This is especially so of the second order frequencies (a ± b), as normally these harmonics fall within the pass-band of the intelligence signal and cause distortion. Therefore the design of the exciter unit, which includes the balanced modulator and translation circuits or mixers, must be very precise. Contrary to the usual push-pull amplifier operation, the balanced modulator circuit condition is such that the tubes must operate on the non-linear portion of their I_a V_g curve, as without this non-linear condition, a balanced modulator could not operate. This in itself tends to produce harmonics because the farther away you get from the pure sine-wave condition, as Fourier's analysis shows, the greater the number of harmonics there will be produced. In the translation stages, it is unfortunate that all practical tubes have a higher order of curvature than would be desired in the theoretical tube, which should have a characteristic curve of only second order curvature. This again tends to create spurious frequencies, and the designer must be careful in his choice of tubes for the balanced modulator and translating circuits. In diagram (11) is shown a typical spurious response chart, to which designers of these circuits must work, indicating the order of spurious frequencies generated when combining two frequencies. Here you will see the smaller frequency on the "Y" axis and the larger frequency on the "X" axis, and the projected curves for the various harmonic relationships show those frequencies that will be produced in the combining process. To avoid those frequencies of second and third order which may cause interference both in the intelligence band and in the adjacent channels, is the designer's problem. Present day techniques generally keep second order products down between 35db and 50 db.



SPURIOUS RESPONSE CHART

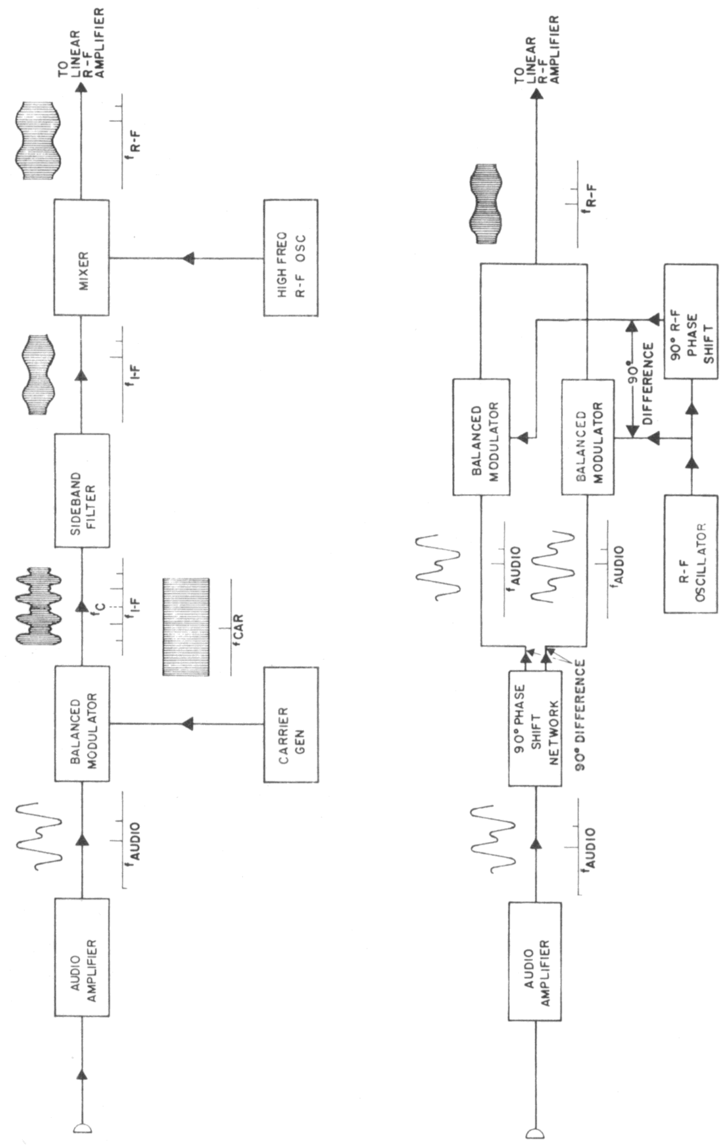
DIAGRAM 11

Diagram (12) depicts the two basic forms of SSB generation showing the wave forms produced in each stage. In the filter system the audio is passed into the balanced modulator, the carrier generator frequency injected to produce the two sidebands, passed through the sideband filter, one sideband is removed and this is fed into a mixer where an R.F. oscillator heterodynes against it to produce the R.F. output signal. This is the common form of SSB generation for commercial and military applications and the one we have been discussing. The filters used in this method, are of three general types, the mechanical filter, crystal lattice type filters or standard LC (Constant K) type filters. The selection of a particular type of filter depends on the cost, availability and general parameters of the circuit required by the designer.

The second method of generating SSB, which is widely used by amateurs, is the "Phase method". It is somewhat operationally more simple and uses two balanced modulators - the balanced modulator being the heart of the SSB exciter system. This is shown on the lower section of diagram 12. Here the audio signal is fed into a phase-shift network that shifts the signal by 90°, the in-phase signal being passed into one balanced modulator and the 90° out-of-phase component being passed into a second balanced modulator. An R.F. oscillator is used to heterodyne against the audio signal to produce the actual output frequency. The output of the R.F. oscillator is heterodyned in the in-phase condition in one instance and through a phase-shift network to produce a 90° shift for the other balanced modulator. Thus the R.F. oscillator output when in-phase will add to the signal, augmenting the sideband, while the output that is in anti-phase will, theoretically, completely balance out the sideband from the other balanced modulator, thus producing the desired effect of SSB. In this method, the R.F. oscillator eliminates much of the circuitry required for the mixers and translating circuits in the "Filter method". However, its disadvantage is that it is difficult to maintain a constant phase shift and consequently the carrier is not always completely attenuated which tends to introduce into the system distortion products. In the phase method type of exciters, second order product supression tends to be in the order of 30db to 35db only.

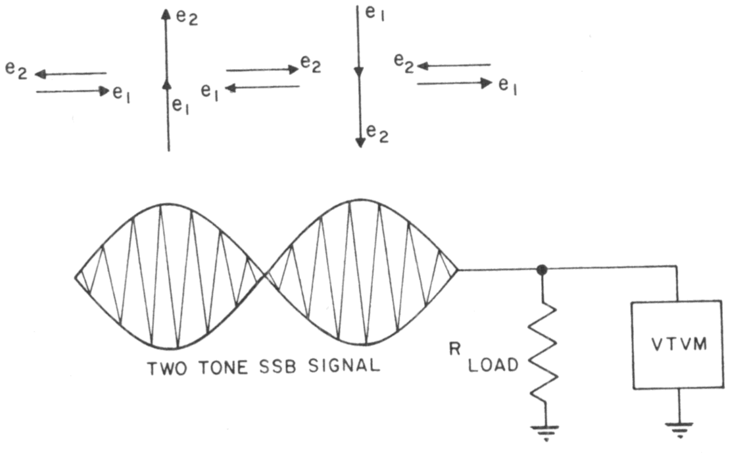
HOW DO WE MEASURE THE POWER OF AN SSB TRANSMITTER?

The power output of an SSB system is usually determined by a two-tone SSB envelope. It is generated by combining two audio tones and then injecting this two-tone signal into the balanced modulator. One sideband is suppressed, leaving the signal sideband in the form shown in



BLOCK DIAGRAM OF A BASIC SINGLE-SIDEBAND GENERATOR

DIAGRAM 12



$V_{vtvm} = (e_1 + e_2)$,

with e_1 and e_2 in phase and rms values

$PEP = V^2_{vtvm}/R_{load} = 4e_1^2/R$ or $4e_2^2/R$, where $e_1 = e_2$

$P_{average} = e_1^2/R + e_2^2/R = 2e_1^2/R$ or $2e_2^2/R$

Therefore: (1) $PEP = V^2_{vtvm}/R$

(2) $P_{average} = 1/2\ PEP$

(3) $P_{tone\ 1}$ or $P_{tone\ 2} = 1/4\ PEP$

POWER MEASUREMENTS FROM TWO-TONE SSB TEST SIGNAL

DIAGRAM 13

diagram (13). The generation of this two-tone envelope is shown by vectors e_2 and e_1. When they are exactly opposite in phase the envelope value is zero and when they are exactly in-phase the envelope value is maximum. This form of signal is used for determining the power output of an SSB system. An SSB transmitter is rated in peak envelope power (PEP) output with the power measured with two equal tone test signals. With such a test signal, the actual watts dissipated in the load is $\frac{1}{2}$PEP. When this signal is fed into a load with a peak reading RMS - calibrated VTVM across the load, it indicates the RMS value of the Peak envelope voltage and is equal to the in-phase sum of $e_1 + e_2$, and since in the two-tone

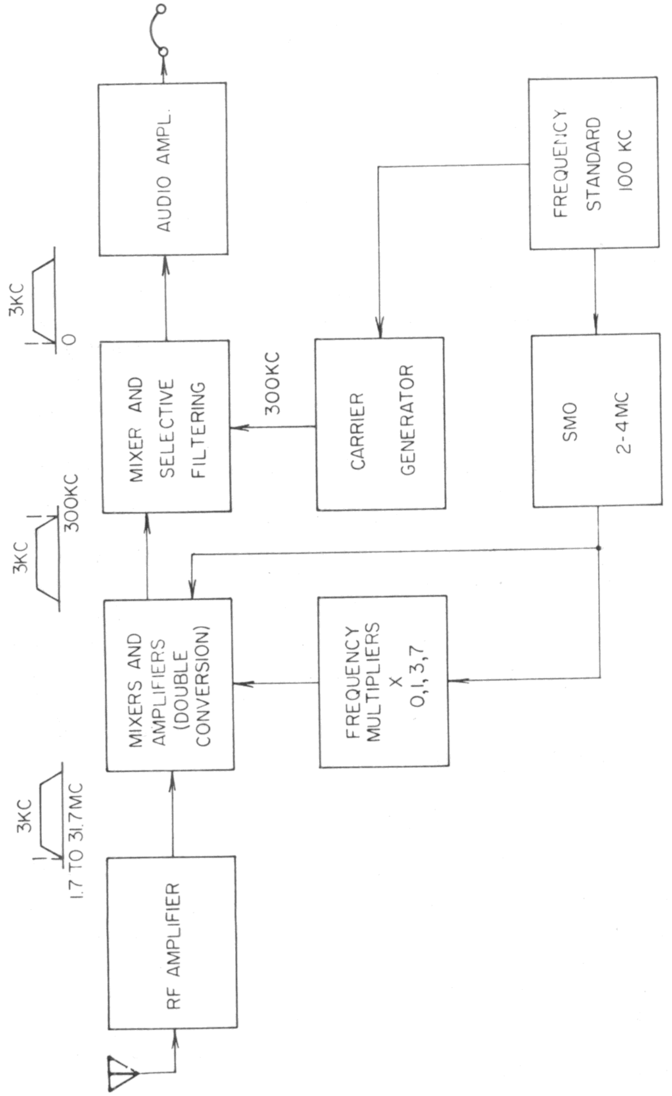
test, signal e_1 equals e_2, the peak envelope power equals $\frac{(2e_1)^2}{R}$ or $\frac{(2e_2)^2}{R}$ and their average power is equal to $\frac{(e_1)^2}{R}$ or $\frac{(e_2)^2}{R}$, therefore the peak envelope power is $\frac{V^2}{R}$ and the "Average power" is $\frac{1}{2}$ PEP.

SSB RECEIVING SYSTEM:

Having discussed the generation of SSB, we must touch on the receiving of the SSB signal. All that is required is an heterodyning system which will convert the received frequency signal back down to its original position in the audio spectrum. A block diagram of such a system is outlined in diagram (14). This SSB receiver is almost identical to a conventional superheterodyne receiver except for the detection circuit. The R. F. signal is amplified and converted down in frequency to a fixed I. F. frequency then the final fixed L. F. Injection frequency is required to bring the signal down to its original position in the audio spectrum. In other words, the carrier is re-inserted. In receiving sideband properly, the carrier must be restored or "Exalted" at the receiver and this may be re-inserted anywhere in the receiver between the antenna and the audio detector. A common method is to re-insert the carrier just before the signal is demodulated by the detector. You have probably heard of "Product Detectors". This is a form of mixing tube where the carrier is re-inserted into the system and detection takes place. The re-inserted carrier should be much larger in voltage than the received signal in order to swamp the grid and cause detection.

SSB STABILITY:

I must point out that the major weakness, if it can be called a weakness, of SSB is that, because of the mixing processes and the narrow band-widths involved, all frequency determining circuits and networks, must possess extreme stability. This calls for crystal-control and highly stable oscillators. As the use of SSB increases, such ancillary equipments as frequency synthesizers are required in order to control all of the translation processes, due mainly because an SSB system really cannot tolerate more than 50 cycles shift in the frequency spectrum for voice communication and even less for multiplex forms of communication, without introducing distortion, loss of signal, or adjacent channel interference.



FUNCTIONAL UNITS OF AN SSB RECEIVING SYSTEM

DIAGRAM 14

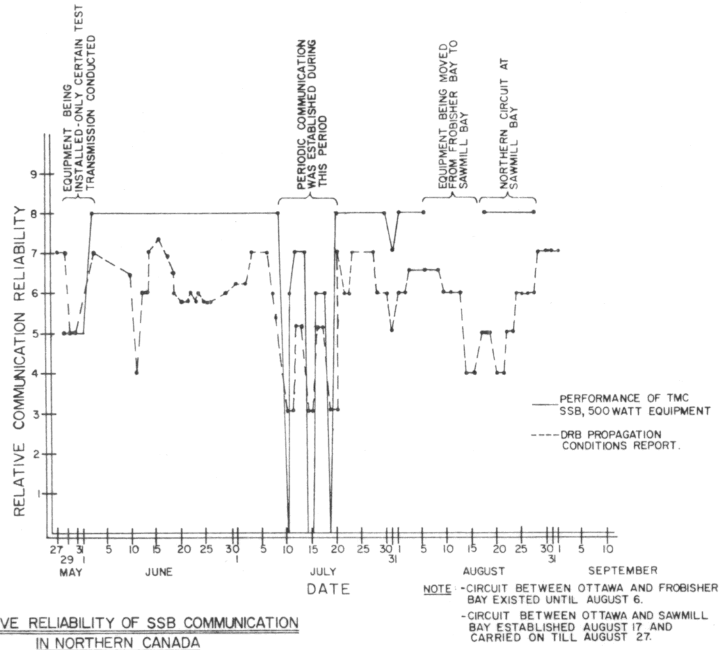
PROOF OF THE PUDDING !

Proof of the pudding, substantiating our talk on the theoretical advantages of SSB over AM is to take a look at an actual operating single sideband circuit which was established by Spartan Air Services Limited between their management offices in Ottawa, Ontario, and their operational survey crews in the Arctic. You are referred to diagram (15) which depicts the actual operating conditions over circuits used by this company. Communications between management and the operational survey crews was essential and time was of major importance in the disposition of the aircraft and crews. You will note from the graph in diagram (15) that the communications circuit extended generally north and south through the auroral zone and that the distances involved were in the order of 2000 Km.

A diagram depicts the relative communications reliability, on a common basis to that in use by "WWV" and the Defence Research Board of Canada, against the date. Superimposed on this graph, for the identical period, are the DRB propagation figures wherever available.

The Single Sideband transmitters in use were 350 watts PEP at both ends of the circuit and the chart covers the period May 27th to September 10th, 1959. Of major interest, during the period covered, is the fact that from July 9th to July 22nd one of the worst known 'blackouts' existed and general radio and line communications were severely disrupted in Canada and most of the Northern Hemisphere. The company's license was restricted in frequency selection but as the graph shows, due to the use of single sideband, they were able to maintain a very high average of communications reliability when other conventional systems, up to and including six times the Spartan output power, failed completely over the same period and similar paths.

A more widespread single sideband network, but covering shorter distances, has been set up by the Hudsons Bay Company with low power equipment. This network is located between British Columbia and Labrador and between latitudes 50°N to 73°N. After changing their network from AM transmission to single sideband, experience has shown that the circuit outage has greatly improved and this has taken place in spite of using low power SSB in lieu of the higher powered AM previously used. Consistent communications is experienced over 200 to 500 mile paths and extend up to 1000 miles in conditions classified as fair or better. It has also been found that reception time on the same frequency,



RELATIVE RELIABILITY OF SSB COMMUNICATION
IN NORTHERN CANADA

DIAGRAM 15

is considerably lengthened over any twenty-four hour period, due chiefly to the narrower bandwidth involved and the virtual absence of forms of selective fading and interference commonly associated with AM communications.

In this same reception area it has been found that it is quite practical to receive SSB signals under conditions where man-made interference by motors, generators, and other types of machinery cause AM signals to be completely unintelligible. Where a 6 kc/s bandwidth has been assigned it is also found that networks may be split up to decrease mutual interference by suitable use of upper or lower sidebands.

ADDENDUM

THE RELATIONSHIP OF PEAK ENVELOPE POWER TO AVERAGE POWER FOR MULTI-TONE S.S.B. OPERATION

INTRODUCTION:

As the number of multi-frequency tones are increased, the relationship of average power to peak envelope power will also vary. Therefore, if a transmitter's rated average power is maintained as the number of tones is increased, the peak envelope power will increase to a figure 5 times the average and if the transmitter is not designed to handle this peak envelope power, damage will occur. In the design and manufacture of quality high and low power transmitters, the Technical Materiel Corporation has taken these parameters into consideration.

This report, by the Technical Materiel Corporation's engineering staff, purports to show the relationship of average power to the peak envelope power, as the number of multitone frequencies is increased.

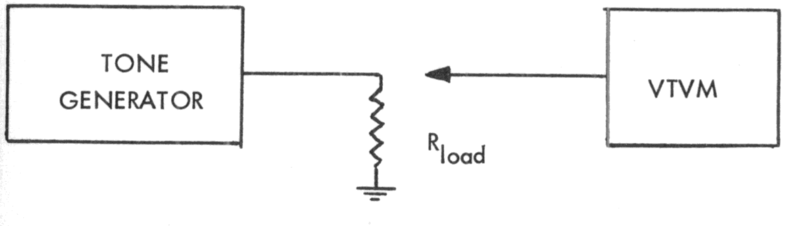


Figure 1.

A peak reading RMS calibrated VTVM, connected across a load R (Figure 1), indicates the RMS value of the peak envelope voltage. This voltmeter reading is equal to the in-phase sum of

$e_1{}^t \; e_2{}^t \; .... \; e_x$ where $e_1, \; e_2 \; .... \; e_x$

are the RMS voltages of the tones $E_1, \; E_2 \; .... \; E_x$

$$\begin{aligned} \text{VTVM} &= e_1 + e_2 + e_3 + ... e_x \\ &= E_1 + E_2 + E_3 + ... E_x \\ &= \sqrt{2} + \sqrt{2} + \sqrt{2} + ...\sqrt{2} \end{aligned}$$

The peak envelope power (PEP) with load is the RMS power developed during the peak cycle:-

$$PEP = \frac{V^2_{vtvm}}{R\ load}$$

$$PEP = \frac{(e_1 + e_2 + \dots\dots\dots e_x)^2}{R\ load} \qquad (1)$$

The average power dissipated in the load is equal to the sum of the power represented by each tone. The average power dissipated is therefore:-

$$P_{avg} = \frac{e_1^{\,2}}{R\ load} + \frac{e_2^{\,2}}{R\ load} + \frac{\dots\dots e_x^{\,2}}{R\ load} \qquad (2)$$

It is assumed that all tones are of equal magnitude, that is to say $E_1 = E_2 = \dots\dots\dots E_x$ or $e_1 = e_2 = \dots\dots\dots e_x$

From equation (1), therefore, the PEP is equal to

$$PEP = \frac{(Xe_x)^2}{R_{load}} = \frac{(X^2 e_x)^2}{R_{load}} \qquad (3)$$

From equation (2), the average power is therefore equal

$$P_{avg} = \frac{(Xe_x)^2}{R_{load}} \qquad (4)$$

The ratio of power average to PEP is:-

$$\text{Ratio} = \frac{P_{avg}}{PEP} = \frac{\dfrac{(Xe_x)^2}{R_{load}}}{\dfrac{(X^2 e_x)^2}{R_{load}}} = \frac{1}{x}$$

Where X is the number of tones.

This relationship is shown on the graph (Diagram 16) as the computed curve.

It was assumed that all of the tones were in phase, which in actual practice does not happen. The following experiment was performed in order to determine the actual relationship of the computed performance to those obtained in practice.

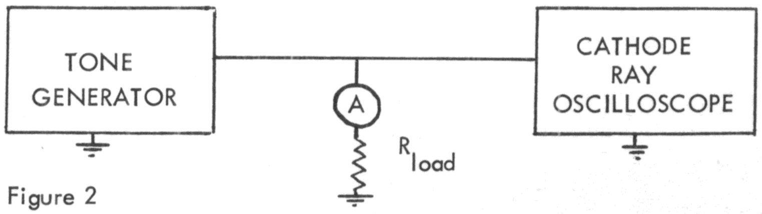


Figure 2

The tone generator was terminated in its nominal impedance. An average reading ammeter was connected into the load circuit. A cathode ray oscilloscope was connected across the load in order to determine the peak voltage at the load:-

$$P_{avg} = R_{load} \times I_{avg}^{\ 2}$$

$$PEP = \frac{(V_{peak}/\sqrt{2})^2}{R_{load}}$$

The ratio of P_{avg} to PEP was taken as $R = \frac{P_{avg}}{PEP}$

This curve is also shown on the graph (Diagram 16) as the experimental curve.

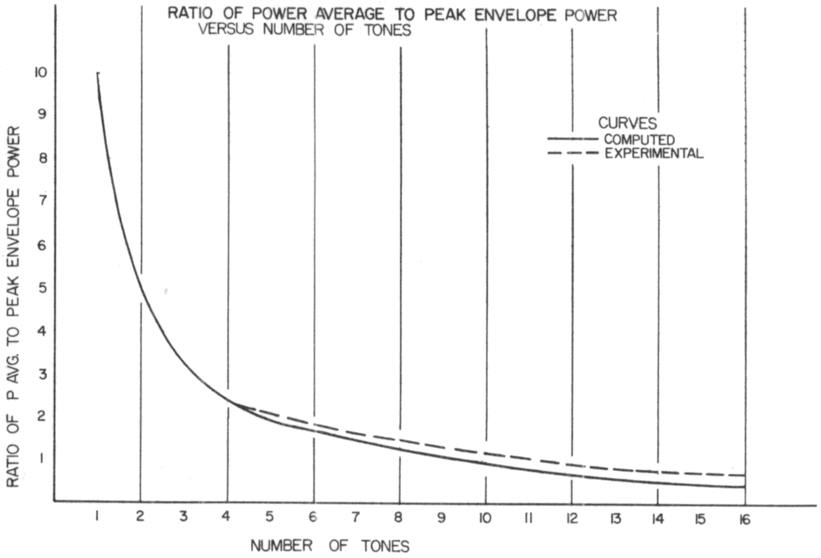


DIAGRAM 16

Notes

PRINTED IN CANADA

SINGLE SIDEBAND

SBT-1K

TRANSMITTER SERIES

AM · FSK · SSB · ISB · CW · FAX

AN/URT-19(V)
AN/FRT-53
AN/FRT-56
AN/FRT-57

TMC Models SBT-1K series of transmitters provide conservatively rated 1 kw PEP output in SSB modes, with Signal to Distortion ratio of 40db, and 1 kw average power in conventional communication modes within the frequency range of 2 to 32 Mcs.

Stabilities of 1 part in 10^6 to synthesized accuracy of 1 part in 10^8, with 100 cps incremental tuning, are featured in this series of transmitters.

The TMC SBT-1K series of transmitters are attractively housed in semi-pressurized cabinets with many customer options for wide band or narrow band audio, antenna tuners, base mount or rugged MIL accepted shipboard mounts for all mobile applications.

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