• Technical Topics—

Suppressed-Carrier A.M.

Among the papers in IRE's single-side-band issue (*Proceedings of the IRE*, December, 1956) there is one describing a double-side-band system[1] devised by John P. Costas, W2CRR, which has been offered as an alternative to s.s.b. The comparative merits of the two systems will probably give rise to considerable controversy — we hope on a level that will develop a higher ratio of light to heat than characterized some of the early s.s.b.-a.m. arguments in amateur circles.

The transmitted signal in this system is double-side-band a.m. without a carrier. Such a signal is no novelty, and the power advantage (in the transmitter) that could be realized over conventional a.m. has been appreciated for many years. The difficulty has been that both side bands cannot be utilized, as a practical matter, on any existing type of receiver, since the carrier must be reinserted at the receiver not only exactly on frequency but also in exactly the right phase. This puts an impossible burden on the conventional-receiver local oscillator.

Dr. Costas has solved the problem by making use of the phase information contained in the two side bands to control the phase of the locally-inserted carrier. This is done by utilizing 90-degree r.f. and a.f. networks in an arrangement that at first glance resembles the s.s.b. reception method based on the phasing system. Full details have not been published, but it appears that such a "synchronous detection" unit would be of about the same complexity as the phasing type "signal slicer" used as an outboard accessory for selectable side-band reception of either s.s.b. or a.m. signals.

Why Detection Is a Problem

The mechanism of detection with a locally-supplied carrier is a basic ingredient of both this and s.s.b. reception, so it is worthwhile to look at it a little more closely. Fig. 1A shows a single side band having a relative frequency distribution more or less typical of voice wave forms. With the frequency scale increasing as shown, this is a lower side band associated with a carrier frequency (normally eliminated at the transmitter and reinserted at the receiver) represented by the vertical line at *O*. Each frequency component in the side band beats against the carrier frequency, in the detector, to produce an audio output frequency equal to the difference between the carrier frequency and the frequency of that component. When the reinserted carrier is properly placed, all the beat tones combine to reproduce the original modulation. In the average voice the maximum amplitude is in the a.f. components in the 200- to 500-cycle region, represented in the drawing by the tallest sideband components.

When this single side band is being received the proper place to put the reinserted carrier frequency is at *O*. Suppose, however, that the tuning is not accurate, resulting in placing the reinserted carrier frequency at *X*. This will cause all the beat tones to be shifted upward in frequency by the number of cycles difference between *O* and *X*. If this difference is not more than a couple of hundred cycles the signal will be quite intelligible still, but will take on a high-pitched and somewhat unnatural characteristic. If the difference becomes too great the intelligibility is lost.

Now imagine the reinserted carrier to be moved in the opposite direction from the correct frequency so that it approaches frequency Y. At first all the beat tones are shifted *downward* by the amount of frequency error, but when the reinserted carrier frequency actually gets into the side band, some components will be on one side of it and some on the other. If the reinserted carrier frequency is at Y, for example, side-band components equally spaced on either side of Y will give the same beat tones. The components to the right of Y come out either higher or lower than they should and those to the left come out too low. Thus the original relationship between the voice components is far more completely destroyed than it was when the reinserted carrier was moved to X. When the reinserted carrier is in the high-amplitude part of the side band most of the beat tones are quite low-pitched,

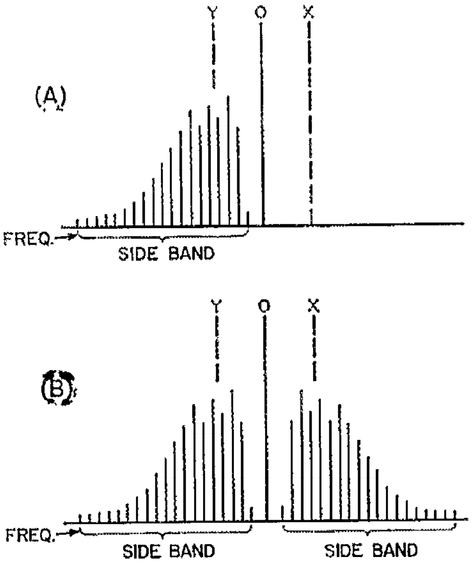

Fig. 1 — (A) Single- and (B) double-side-band signals with properly-placed reinserted carrier (O) and mistuned carriers (X and Y).

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[1] Costas, "Synchronous Communications," *Proc. IRE*, December, 1956.

giving a sort of "whump-awk" effect with no intelligibility. The received signal deteriorates more rapidly when the carrier frequency is moved in this direction than it does when it is moved the same number of cycles in the other direction.

Detection with D.S.B.

When both side bands are present, mistuning of the reinserted carrier causes both effects to be present simultaneously. If, in Fig. 1B, the reinserted carrier is moved from its proper frequency, *O*, to *X*, the lower side band (to the left of *O*) will give a detector output corresponding to that described in connection with Fig. 1A with the reinserted carrier at *X*. This part of the detector output will be intelligible to the same extent as in the single-side-band case.

However, the higher side band (to the right of *O*) will give the same sort of output as was obtained when the reinserted carrier was at *Y* in Fig. 1A. Thus an unintelligible signal is superimposed on the intelligible one. It is exactly like a properly-tuned s.s.b. signal being interfered with by another equal-amplitude s.s.b. signal on a slightly different suppressed-carrier frequency. With concentration, the desired message can be copied, but the interference cannot be escaped unless one of the side bands is rejected by the receiver before detection. This is so even though the error in the reinserted carrier frequency may be very small; an error of a few cycles gives the voice a "gravelly" sound that disappears only when the reinserted frequency is exactly right. Even then a very slow frequency drift will give a "rollover" effect like selective fading because of the change in phase of the side bands with respect to the carrier.

Although rejecting one of the side bands will eliminate the self-interference, the tuning continues to be more critical than it is with s.s.b. This is because the unused side band must be highly attenuated in order to avoid the effects described above. This can be done satisfactorily when the receiver has a pass band with high skirt selectivity, but any mistuning which allows a part of the undesired side band to get into the pass band prevents "clearing up" the signal just as much as though the receiver had nothing more than conventional selectivity.

D.S.B. vs. Other Systems

A comparison between s.s.b. and suppressed-carrier double-side-band a.m. should of course be based on proper and complete utilization of each system at both the receiver and transmitter. As applied to amateur communication, such a comparison would have to be purely theoretical at the present time because there are no synchronous-detection receivers in use, nor is there any information available on how to convert existing receivers to synchronous detection. Because of this and other factors we do not propose to discuss s.s.b. *vs.* suppressed-carrier a.m. at this stage. Instead, let's examine what suppressing the carrier of an a.m. signal might offer in the way of advantages over conventional a.m. transmission with a full carrier, using receivers available now.

Side-Band Power

When side-band power is under consideration the question of wave form always has to be settled — usually by choosing single-tone modulation because it is simple to handle. The results are then extrapolated to cover voice wave forms with a few generalities about the differences between them and sine-wave tones. Since this is about the only usable procedure, it will be followed here. There is good justification for it since the two systems being compared are both a.m. With modulation of this type the envelope of a carrier modulated 100 per cent is shown in the familiar pattern of Fig. 2A. The modulation envelope of a suppressed-carrier a.m. signal having the same peak-envelope power is shown in Fig. 2B; this is the "two-tone signal" well known to s.s.b. operators who own oscilloscopes and use them.

In the envelope of Fig. 2A the average side-band power is equal to one-half the carrier power, which in turn is equal to one-fourth of the peak-envelope power — all very familiar relationships. Since $\frac{1}{2} \times \frac{1}{4} = \frac{1}{8}$, the average side-band power is one-eighth the peak-envelope power, and further is equally divided between the two side bands. Thus each side band has one-sixteenth of the peak-envelope power.

In Fig. 2B the power is all side-band power, since there is no carrier. With this envelope shape

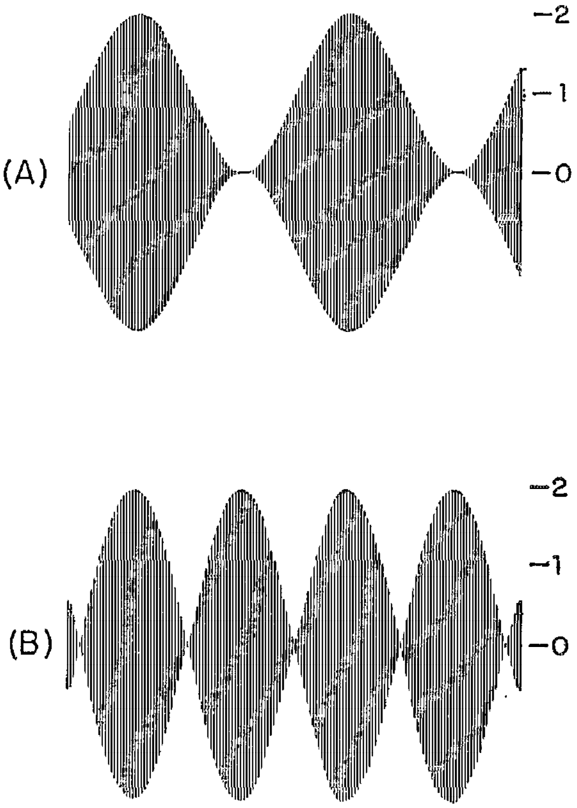

Fig. 2 — A — Envelope of 100-per-cent modulated a.m. signal with sinusoidal modulation; B — envelope of suppressed-carrier signal with sinusoidal modulation. The peak-envelope amplitude is the same in both cases.

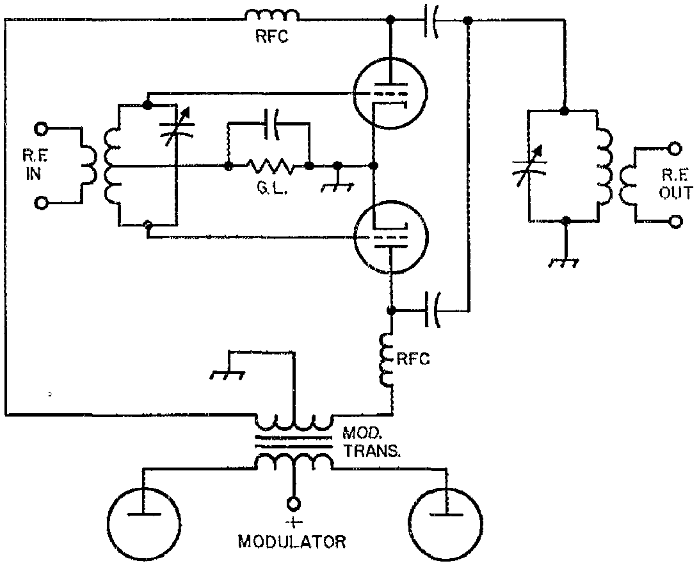

Fig. 3 — **Basic plate-modulation circuit for producing a suppressed-carrier a.m. signal, using high-level modulation. The principles of balanced modulators apply. Both r.f. circuits (grid and plate) operate at the r.f. signal frequency. The suppressed-carrier signal also may be generated at low level and amplified by linear amplifiers.**

the average power is equal to one-half the peak-envelope power. Comparing this with the side-band power in the conventional a.m. signal, the ratio is ½ ÷ ⅛, or 4 to 1. That is, the side-band power in a suppressed-carrier a.m. signal is four times as great as in a full-carrier 100-per-cent-modulated a.m. signal, assuming the same peak-envelope power in both cases. The power is still divided equally between the two side bands, so the power in one side band of a suppressed-carrier d.s.b. signal is equal to one-fourth of the peak-envelope power.

Tube Operation

A natural question here is this: Will the same tube or tubes handle the same peak-envelope power with both types of signal?

The plate loss with either signal is equal to the difference between the average power input and average power output. The average power in the conventional a.m. signal is 1.5 times the carrier power, or, from the figures above, ⅜ of the peak-envelope power (1½ × ¼). In the suppressed-carrier signal the average power is ½ the peak-envelope power, as previously stated. If the modulated stage operates at constant efficiency — e.g., plate modulation — the plate loss will be the same with either type of signal when the average power output is the same. For equal average-power outputs, the peak-envelope power in the suppressed-carrier case must be reduced to three-fourths of the permissible peak-envelope power with conventional carrier, so on a plate-dissipation basis the side-band-power advantage of suppressed-carrier transmission is 3 to 1, not 4 to 1.

Now this is all clear-cut and logical enough, but applies strictly only in the case of continuous single-tone modulation. It serves principally as a take-off point for applying factors determined (very often, at least) by the optimism of the estimator and his enthusiasm for one or the other side of the argument. It is known, for example, that the average power of voice wave forms is generally low as compared with a sine wave. Because in suppressed-carrier transmission there is no continuous plate dissipation (amounting to at least two-thirds of the total dissipation in the case of conventional a.m.) advantage also can be taken of the low duty cycle in speech transmission. However, the peak-envelope output cannot be pushed up indefinitely; this would overload the tubes with respect to either plate voltage or plate current, or both, even though the plate loss might be below rating.

Possibly the best conclusion to reach in this case is that with suppressed-carrier a.m. the peak-envelope rating, rather than plate dissipation, is the limiting factor, and that this rating should be the same as with full-carrier a.m. (double the carrier-only values of d.c. plate voltage and plate current). This restores the 4-to-1 power advantage. It might be argued that this is somewhat unfair to carrier a.m., since the plate dissipation will not rise 50 per cent with voice modulation as it does with a sine-wave modulating signal. Taking this into account would permit perhaps 25 per cent greater input and output, but would lead to excessive peak-envelope input in the carrier a.m. case. The details cannot be resolved without study of the maximum ratings and characteristics of the particular types of tubes considered.

Plate Modulation

The suppressed-carrier signal can be generated by using any of several forms of balanced modulators; the technique is familiar from s.s.b. operation. With plate modulation, the basis of the figures given above, the essentials of a typical circuit are given in Fig. 3. The plates of the r.f. amplifier (two tubes are required) must be driven with out-of-phase (push-pull) audio voltages from the modulator; this requires a modulation transformer having a center-tapped secondary. The r.f. circuit shown has push-pull drive to the grids, with the plates connected in parallel. This arrangement can be reversed, if desired, so the grids are driven in parallel and the plate circuit is arranged in push-pull. The actual tubes could

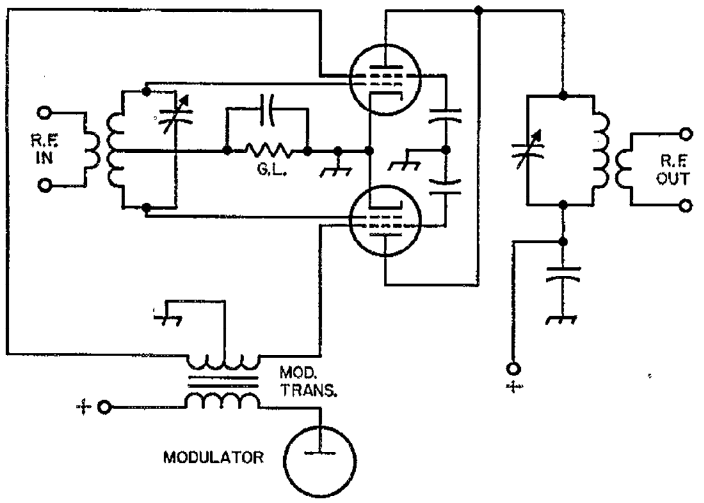

Fig. 4 — **Basic screen-modulation circuit for suppressed-carrier a.m. In a practical circuit it may be desirable to use a small amount of negative bias on the screens in order to improve the linearity at the "crossover" point (zero axis in Fig. 2-B).**

be pentodes or tetrodes, of course, with the usual dropping resistor (two required here) for reducing the audio voltage applied to the screens. There are no d.c. voltages on the plates and screens, but the control-grid bias and excitation should be normal for the tube types.

It must be realized that the plate input power is supplied entirely by the a.f. amplifier. There is no increase in side-band power output merely because the carrier is eliminated. With any plate-modulation system the actual side-band power is the power output of the modulator multiplied by the plate efficiency of the modulated amplifier. Thus a given Class B modulator will give the same "talk power" with either system, and if more side-band power is wanted, it has to be supplied through the medium of increased audio-frequency power.

Grid Modulation

Since suppressed-carrier transmission offers no possibility of saving audio power with plate modulation, it is probably of more interest to compare it with conventional a.m. when some form of grid-bias modulation is used. With carrier a.m., the rule of thumb is that the carrier power output is equal to one-half the rated plate dissipation of the modulated-amplifier tube or tubes. This is because the plate efficiency at the unmodulated-carrier level is just one-half its value at the peak-envelope level, and the efficiency at the latter level is assumed to be ⅔. (The actual peak efficiency will vary somewhat with different tubes and the choice of operating conditions, but the figure of ⅔ or 66 per cent is a fair-enough average.)

If the linearity of a grid-bias-modulated amplifier is good, the average efficiency when generating the type of wave form shown in Fig. 2B will equal 0.636 times the peak-envelope efficiency. At full output, then, the average plate efficiency will be 0.636 × ⅔, or 42.4 per cent. Thus the plate loss with carrier a.m. is 1 − 0.333 = 0.666, and with suppressed-carrier a.m. is 1 − 0.424 = 0.576. The plate input therefore can be increased in the ratio 0.666/0.576, or 1.15 to 1, when the carrier is suppressed. This increases the peak-envelope power in the same ratio. Hence the comparative side-band power is 4 × 1.15 = 4.6 to 1. A 15 per cent increase in peak-envelope power input is not likely to exceed any tube ratings in this case.

However, the comparison again is on the basis of continuous sine-wave modulation. Voice wave forms can be neglected in the full-carrier case, since the limiting condition of maximum dissipation is reached during those necessary pauses when there is no modulation. With the carrier suppressed, though, the situation is similar to that occurring with a linear amplifier on s.s.b. The limit to peak-envelope power here is where the rising curve of optimism intersects the descending curve of caution — or, in practice, where the amplifier flashes over, since the safe operating plate voltage (rather than plate dissipation) is usually the determining factor. Multiplying by 2 is probably reasonable with most tubes, so it is no doubt fair to say that, using grid-bias modulation, about 8 times as much side-band power can be obtained from a given tube by suppressing the carrier.

A basic screen-modulation circuit for the purpose is given in Fig. 4. The r.f. connections are similar to those in Fig. 3, but the modulating signal is applied in push-pull to the screens. This is a rather common form of balanced modulator.

Enter the Receiver

Comparisons of this nature are valid from the transmitting standpoint, but are indicative of actual over-all results only when the full side-band output is utilized at the receiving end. This is done in the case of standard a.m. In the case of suppressed-carrier a.m. both side bands can be used only by a receiver having the synchronous-detection system with ordinary detectors, as pointed out earlier, one of the side bands *has to be rejected* in the receiver, turning the signal into s.s.b. before demodulation. This requires selectivity of the same order as is incorporated in modern selectable-side-band receivers.

When only one of the two side bands is utilized, half the received power is thrown away. Because of the mechanics of detection the two side bands of a conventional a.m. signal, properly combined, produce four times as much audio power output as one side band alone. There is thus a 4-to-1 loss in "talk power" associated with the receiving method.[2] However, since the receiver band width is one-half that required for reception of both side bands, there is a 2-to-1 reduction in noise power, so the over-all reduction in signal-to-noise ratio is 2 to 1, not 4 to 1. Applying this figure to those worked out earlier we have, for the presently-realizable improvement in signal-to-noise ratio using suppressed-carrier *vs.* full-carrier a.m., 2 to 1 (3 db.) in the case of plate modulation (provided the audio power output of the modulator is quadrupled), and 4 to 1 (6 db.) in the case of grid-bias modulation.

These figures are not quite the whole story. One of the principal benefits of s.s.b. in amateur communication is the absence of a carrier, both in the kind of break-in operating it makes possible and in the elimination of heterodyne QRM. Suppressed-carrier a.m. offers comparable voice break-in possibilities and the same freedom from heterodyne interference. It does not reduce the total band width occupied by an a.m. signal, which is why we do not consider it an ultimate "competitor" of s.s.b. in the amateur field. Rather, it seems to us to be an intermediate step — in the right direction, certainly, since any system that leads to the eventual elimination of phone carriers will contribute to better conditions in the phone bands.

A point in its favor, at least for those of us who still build our own equipment, is the simplicity of the transmitter as compared with s.s.b. circuits. Balanced modulators of the types discussed are nearly as easy to adjust as ordinary plate- and grid-modulation circuits. The practical construction of a grid-bias modulation amplifier of this type was shown by the writer in the June, 1951 issue of *QST*;[3] designed for reduced-carrier transmission, this circuit included provision for inserting a desired amount of carrier at the transmitter so the signal could be demodulated in an ordinary receiver. It can be used for suppressed-carrier transmission simply by omitting the positive bias on the carrier-tube screen.

— *G. G.*

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[2] For a more detailed discussion of this point see "The A.M. Equivalent of Single Sideband," *QST*, January, 1954.

[3] Grammer, "Practical D.S.R.C. Transmitter Design," *QST*, June, 1951. The principles of the system — which can be considered to be the general case of amplitude modulation, with full-carrier and suppressed-carrier signals as limiting cases — were described in the May, 1951 issue.

VE5s Aid Meteor Observers

LATE LAST SUMMER the Regina Astronomical Society approached VE5XX, president of the Regina Amateur Radio Association, about using amateur radio facilities to handle traffic between several observing points in connection with the Perseid Meteor Shower. The type of traffic to be handled related to time checks, counts, and photographic data.

Despite some problems in manpower and equipment the Regina ARA successfully provided communications for the Regina Astronomical Society and contributed materially to the satisfactory meteor observations and the collection of data. An indication of the volume of activity and traffic is the fact that for a time meteors were being recorded at the rate of 60 per hour.

One of the lessons learned included the desirability of using something other than 75 meters at a time and season when aurora was prevalent. Also, the necessity for having some good portable gear at hand and the necessity for providing plenty of relief operators for extended operations were other points brought home.

Still another by-product of the sessions was the interests in the opposite hobbies stirred up amongst the radio and astronomy enthusiasts.

Those participating in the planning and accomplishment of an exercise which was of good practical use and good public relations included VE5s CG, CM, DG, FG, GB, GH, HN, JK, JW, LU, WM, WW and XX.

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Regina Astronomical Society base line crew operating in VE5LU's potato patch at his farm site. From left to right, George McNeely, John V. Hodges, and Bill Clipsham. — *Photo by VE5XX*

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