SSB GENERATION - THE PHASING METHOD

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ACHIEVEMENTS: *introduction to the QUADRATURE PHASE SPLITTER module (QPS); modelling the phasing method of SSB generation; estimation of sideband suppression; definition of PEP.*

PREREQUISITES: *an acquaintance with DSBSC generation, as in the experiment entitled* ***DSBSC generation****, would be an advantage.*

PREPARATION

There are three well known methods of SSB generation using analog techniques, namely the *filter* method, the *phasing* method, and *Weaver's* method. This experiment will study the phasing method.

the filter method

You have already modelled a DSBSC signal.

An SSB signal may be derived from this by the use of a suitable bandpass filter - commonly called, in this application, an SSB sideband filter. This, the *filter method*, is probably the most common method of SSB generation. Mass production has given rise to low cost, yet high performance, filters. But these filters are generally only available at 'standard' frequencies (for example 455 kHz, 10.7 MHz) and SSB generation by the filter method at other frequencies can be expensive. For this reason TIMS no longer has a 100 kHz SSB filter module, although a decade ago these were in mass production and relatively inexpensive [1].

the phasing method

The *phasing method* of SSB generation, which is the subject of this experiment, does not require an expensive filter, but instead an accurate phasing network, or *quadrature phase splitter* (QPS). It is capable of acceptable performance in many applications.

[1] analog frequency division multiplex, where these filters were used, has been superseded by time division multiplex

The QPS operates at *baseband*, no matter what the carrier frequency (either intermediate or final), in contrast to the filter of the filter method.

Weaver's method

In 1956 Weaver published a paper on what has become known either as 'the third method', or 'Weaver`s method', of SSB generation [2].

Weaver's method can be modelled with TIMS - refer to the experiment entitled *Weaver`s SSB generator* (within *Volume A2 - Further & Advanced Analog Experiments*).

the SSB signal

Recall that, for a single tone message cosμt, a DSBSC signal is defined by:

$$\text{DSBSC} = A.\cos\mu t.\cos\omega t \qquad \text{......... 1}$$

$$= A/2.\cos(\omega - \mu)t + A/2.\cos(\omega + \mu)t \qquad \text{......... 2}$$

$$= \text{lower sideband} + \text{upper sideband} \qquad \text{......... 3}$$

When, say, the lower sideband (LSB) is removed, by what ever method, then the upper sideband (USB) remains.

$$\text{USB} = A/2.\cos(\omega + \mu)t \qquad \text{......... 4}$$

This is a single frequency component at frequency $(\omega + \mu)/(2.\pi)$ Hz. It is a (co)sine wave. Viewed on an oscilloscope, with the time base set to a few periods of ω, it looks like any other sinewave.

What is its envelope ?

the envelope

The USB signal of eqn. (4) can be written in the form introduced in the experiment on ***Envelopes*** in this Volume. Thus:

$$\text{USB} = a(t).\cos[(\omega + \mu)t + \varphi(t)] \qquad \text{........ 5}$$

The envelope has been defined as:

$$\text{envelope} = |\, a(t)\, | \qquad \text{........ 6}$$

$$= A/2 \qquad \text{[from eqn. (4)]} \qquad \text{........ 7}$$

Thus the envelope is a constant (ie., a straight line) and the oscilloscope, correctly set up, will show a rectangular band of colour across the screen.

This result may seem at first confusing. One tends to ask: 'where is the message information' ?

[2] Weaver, D.K., "A third method of generation and detection of single sideband signals", *Proc. IRE*, Dec. 1956, pp. 1703-1705

> ***answer***: *the message amplitude information is contained in the amplitude of the SSB, and the message frequency information is contained in the frequency* ***offset,*** *from ω, of the SSB.*

An SSB derived from a single tone message is a very simple example. When the message contains more components the SSB envelope is no longer a straight line. Here is an important finding !

> *An ideal SSB generator, with a single tone message, should have a straight line for an envelope.*

Any deviation from this suggests extra components in the SSB itself. If there is only one extra component, say some 'leaking' carrier, or an unwanted sideband not completely suppressed, then the amplitude and frequency of the envelope will identify the amplitude and frequency of the unwanted component.

generator characteristics

A most important characteristic of any SSB generator is the amount of out-of-band energy it produces, relative to the wanted output. In most cases this is determined by the degree to which the unwanted sideband is suppressed [3]. A ratio of wanted-to-unwanted output power of 40 dB was once considered acceptable commercial performance; but current practice is likely to call for a suppression of 60 dB or more, which is not a trivial result to achieve.

a phasing generator.

The phasing method of SSB generation is based on the addition of two DSBSC signals, so phased that their upper sidebands (say) are identical in phase and amplitude, whilst their lower sidebands are of similar amplitude but opposite phase.

The two out-of-phase sidebands will cancel if added; alternatively the in-phase sidebands will cancel if subtracted.

The principle of the SSB phasing generator in illustrated in Figure 1.

Notice that there are two 90° phase changers. One operates at carrier frequency, the other at message frequencies.

The carrier phase changer operates at a single, fixed frequency, ω rad/s.

The message is shown as a single tone at frequency μ rad/s. But this can lie anywhere within the frequency range of speech, which covers several octaves. A network providing a constant 90° phase shift over this frequency range is very difficult to design. This would be a *wideband phase shifter*, or *Hilbert transformer*.

[3] but this is not the case for Weaver's method

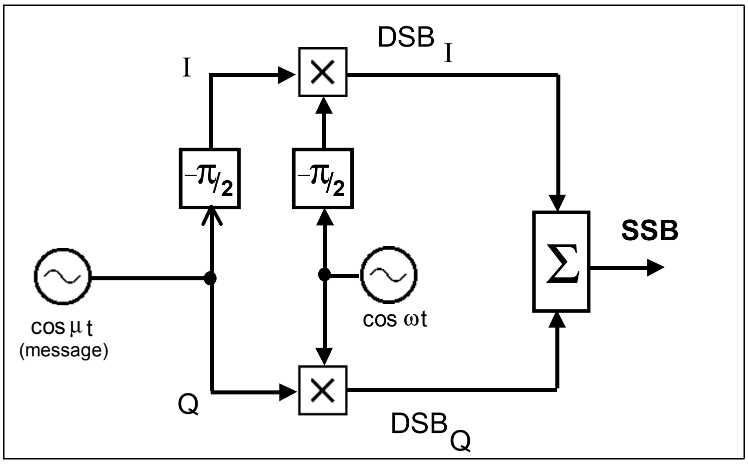

Figure 1: principle of the SSB Phasing Generator

In practice a wideband phase *splitter* is used. This is shown in the arrangement of Figure 2.

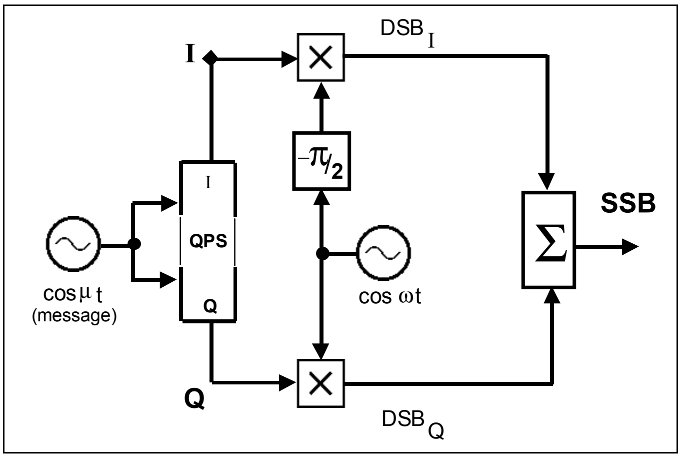

Figure 2: practical realization of the SSB phasing generator

The wideband phase *splitter* consists of two complementary networks - say **I** (inphase) and **Q** (quadrature). When each network is fed from the same input signal the phase difference between the two outputs is maintained at 90°. Note that the phase difference between the common input and either of the outputs is not specified; it is not independent of frequency.

Study Figures 1 and 2 to ensure that you appreciate the difference.

At the single frequency µ rad/s the arrangements of Figure 1 and Figure 2 will generate two DSBSC. These are of such relative phases as to achieve the cancellation of one sideband, and the reinforcement of the other, at the summing output.

You should be able to confirm this. You could use graphical methods (phasors) or trigonometrical analysis.

The QPS may be realized as either an active or passive circuit, and depends for its performance on the accuracy of the components used. Over a wide band of audio frequencies, and for a common input, it maintains a phase difference between the two outputs of 90 degrees, with a small frequency-dependant error (typically equiripple).

performance criteria

As stated earlier, one of the most important measures of performance of an SSB generator is its ability to eliminate (suppress) the unwanted sideband. To measure the ratio of wanted-to-unwanted sideband suppression directly requires a SPECTRUM ANALYSER. In commercial practice these instruments are very expensive, and their purchase cannot always be justified merely to measure an SSB generator performance.

As always, there are indirect methods of measurement. One such method depends upon a measurement of the SSB envelope, as already hinted.

Suppose that the output of an SSB generator, when the message is a single tone of frequency μ rad/s, consists only of the wanted sideband W and a small amount of the unwanted sideband U.

It may be shown that, for $U \ll W$, the envelope is nearly sinusoidal and of a frequency equal to the frequency difference of the two components.

Thus the envelope frequency is (2μ) rad/s.

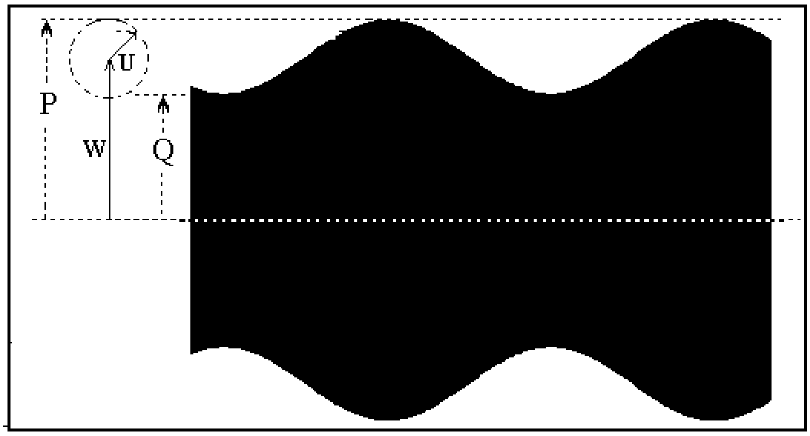

Figure 3 : measuring sideband suppression via the envelope

It is a simple matter to measure the peak-to-peak and the trough-to-trough amplitudes, giving twice P, and twice Q, respectively. Then:

$$P = W + U \qquad \text{................ 6}$$

$$Q = W - U \qquad \text{................ 7}$$

as seen from the phasor diagram. This leads directly to:

$$\text{sideband suppression} = 20\log_{10}[\frac{P+Q}{P-Q}]\ dB \qquad \text{........ 8}$$

If U is in fact the sum of several small components then an estimate of the wanted to unwanted power ratio can still be made. Note that it would be greater (better) than for the case where U is a single component.

A third possibility, the most likely in a good design, is that the envelope becomes quite complex, with little or no stationary component at either μ or μ/2; in this case the unwanted component(s) are most likely system noise.

Make a rough estimate of the envelope magnitude, complex in shape though it may well be, and from this can be estimated the wanted to unwanted suppression ratio, using eqn.(8). This should turn out to be better than 26 dB in TIMS, in which case the system is working within specification. The TIMS QPS module does not use precision components, nor is it aligned during manufacture. It gives only a moderate sideband suppression, but it is ideal for demonstration purposes.

Within the 'working frequency range' of the QPS the phase error from 90^0 between the two outputs will vary with frequency (theoretically in an equi-ripple manner).

EXPERIMENT

the QPS

Refer to the *TIMS User Manual* for information about the QUADRATURE PHASE SPLITTER - the 'QPS'.

Before patching up an SSB phasing generator system, first examine the performance of the QUADRATURE PHASE SPLITTER module. This can be done with the arrangement of Figure 4.

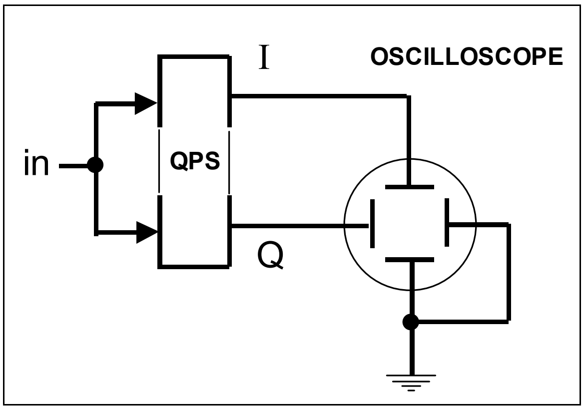

Figure 4: arrangement to check QPS performance

With the oscilloscope adjusted to give equal gain in each channel it should show a circle. This will give a quick confirmation that there *is* a phase difference of approximately 90 degrees between the two output sinewaves at the measurement frequency. Phase or amplitude errors should be too small for this to degenerate visibly into an ellipse. The measurement will also show the bandwidth over which the QPS is likely to be useful.

T1 *set up the arrangement of Figure 4. The oscilloscope should be in* ***X-Y*** *mode, with equal sensitivity in each channel. For the input signal source use an AUDIO OSCILLATOR module. For correct QPS operation the display should be an approximate circle. We will not attempt to measure phase error from this display.*

T2 *vary the frequency of the AUDIO OSCILLATOR, and check that the approximate circle is maintained over at least the speech range of frequencies.*

phasing generator model

When satisfied that the QPS is operating satisfactorily, you are now ready to model the SSB generator. Once patched up, it will be necessary to adjust amplitudes and phases to achieve the desired result. A hit-and-miss method can be used, but a systematic method is recommended, and will be described now.

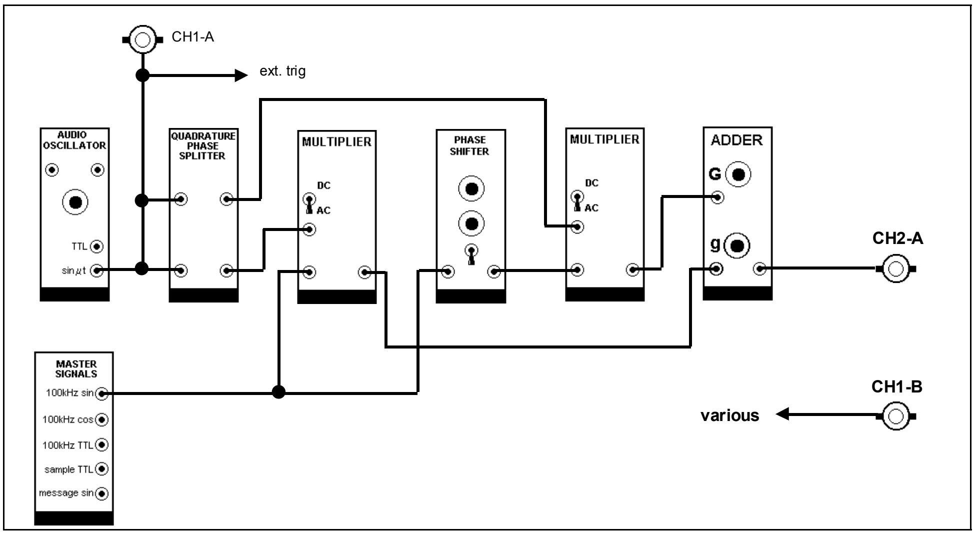

Figure 5: the SSB phasing generator model

T3 *patch up a model of the phasing SSB generator, following the arrangement illustrated in Figure 5. Remember to set the on-board switch of the PHASE SHIFTER to the 'HI' (100 kHz) range before plugging it in.*

T4 *set the AUDIO OSCILLATOR to about 1 kHz*

T5 *switch the oscilloscope sweep to 'auto' mode, and connect the 'ext trig' to an output from the AUDIO OSCILLATOR. It is now synchronized to the message.*

T6 *display one or two periods of the message on the upper channel CH1-A of the oscilloscope for reference purposes. Note that this signal is used for external triggering of the oscilloscope. This will maintain a stationary envelope while balancing takes place. Make sure you appreciate the convenience of this mode of triggering.*

Separate DSBSC signals should already exist at the output of each MULTIPLIER. These need to be of equal amplitudes at the *output* of the ADDER. You will set this up, at first approximately and independently, then jointly and with precision, to achieve the required output result.

T7 *check that out of each MULTIPLIER there is a DSBSC signal.*

T8 *turn the ADDER gain '**G**' fully anti-clockwise. Adjust the magnitude of the other DSBSC, '**g**', of Figure 5, viewed at the ADDER output on CH2-A, to about 4 volts peak-to-peak. Line it up to be coincident with two convenient horizontal lines on the oscilloscope graticule (say 4 cm apart).*

T9 *remove the '**g**' input patch cord from the ADDER. Adjust the '**G**' input to give approximately 4 volts peak-to-peak at the ADDER output, using the same two graticule lines as for the previous adjustment.*

T10 *replace the '**g**' input patch cord to the ADDER.*

The two DSBSC are now appearing simultaneously at the ADDER output.

Now use the same techniques as were used for balancing in the experiment entitled *Modelling an equation* in this Volume. Choose *one* of the ADDER gain controls ('**g**' or '**G**') for the amplitude adjustment, and the PHASE SHIFTER for the carrier phase adjustment.

The aim of the balancing procedure is to produce an SSB at the ADDER output.

The amplitude and phase adjustments are non-interactive.

performance measurement

Since the message is a sine wave, the SSB will *also* be a sine wave when the system is correctly adjusted. *Make sure you agree with this statement before proceeding*.

The oscilloscope sweep speed should be such as to display a few periods of the message across the full screen. This is so that, when looking at the SSB, a stationary *envelope* will be displayed.

Until the system is adjusted the display will look more like a DSBSC, or even an AM, than an SSB.

Remote from balance the envelope should be stationary, but perhaps not sinusoidal. As the balance condition is approached the envelope will become roughly sinusoidal, and its amplitude will reduce. Remember that the pure SSB is going to be a sinewave [4]. As discussed earlier, if viewed with an appropriate time scale, which you have already set up, this should have a *constant ('flat') envelope*.

This is what the balancing procedure is aiming to achieve.

T11 *balance the SSB generator so as to minimize the* ***envelope*** *amplitude. During the process it may be necessary to increase the oscilloscope sensitivity as appropriate, and to shift the display vertically so that the envelope remains on the screen.*

T12 *when the best balance has been achieved, record results, using Figure 3 as a guide. Although you need the magnitudes P and Q, it is more accurate to measure*

a) 2P directly, which is the peak-to-peak of the SSB

b) Q indirectly, by measuring (P-Q), which is the peak-to-peak of the ***envelope****.*

As already stated, the TIMS QPS is not a precision device, and a sideband suppression of better than 26 dB is unlikely.

You will *not* achieve a perfectly flat envelope. But its amplitude may be small or comparable with respect to the noise floor of the TIMS system.

The presence of a residual envelope can be due to any one or more of:

- leakage of a component at carrier frequency (a fault of one or other MULTIPLIER [5])
- incomplete cancellation of the unwanted sideband due to imperfections of the QPS [6].
- distortion components generated by the MULTIPLIER modules.
- other factors; can you suggest any ?

Any of the above will give an envelope ripple period comparable with the period of the message, rather than that of the carrier. *Do you agree with this statement ?*

If the envelope shape is sinusoidal, and the frequency is:

- twice that of the message, then the largest unwanted component is due to incomplete cancellation of the unwanted sideband.
- the same as the message, then the largest unwanted component is at carrier frequency ('carrier leak').

[4] for the case of a single-tone message, as you have

[5] the TIMS user is not able to make adjustments to a MULTIPLIER balance

[6] there is no provision for adjustments to the QPS

If it is difficult to identify the shape of the envelope, then it is probably a combination of these two; or just the inevitable system noise. An engineering estimate must then be made of the wanted-to-unwanted power ratio (which could be a statement of the form 'better than 45 dB'), and an attempt made to describe the nature of these residual signals.

T13 *if not already done so, use the FREQUENCY COUNTER to identify your sideband as either upper (USSB) or lower (LSSB). Record also the exact frequency of the message sine wave from the AUDIO OSCILLATOR. From a knowledge of carrier and message frequencies, confirm your sideband is on one or other of the expected frequencies.*

To enable the sideband identification to be confirmed analytically (see Question below) you will need to make a careful note of the model configuration, and in particular the sign and magnitude of the phase shift introduced by the PHASE SHIFTER, and the sign of the phase difference between the ***I*** *and* ***Q*** *outputs of the QPS. Without these you cannot check results against theory.*

degree of modulation - PEP

The SSB generator, like a DSBSC generator, has no 'depth of modulation', as does, for example, an AM generator [7]. Instead, the output of an SSB transmitter may be increased until some part of the circuitry overloads, giving rise to unwanted distortion components. In a good practical design it is the output amplifier which should overload first [8]. When operating just below the point of overload the transmitter output amplifier is said to be producing its maximum *peak* output power - commonly referred to as the 'PEP' - an abbreviation for 'peak envelope power'.

Depending upon the nature of the message, the amplifier may already have exceeded its maximum *average* power output capability. This is generally so with tones, or messages with low peak-to-average power waveform, but not so with speech, which has a relatively high peak-to-average power ratio of approximately 14 dB.

When setting up an SSB transmitter, the message amplitude must be so adjusted that the rated PEP is not exceeded. This is not a trivial exercise, and is difficult to perform without the appropriate equipment.

[7] which has a fixed amplitude carrier term for reference.

[8] why ?

determining rated PEP

The setting up procedure for an SSB transmitter assumes a knowledge of the transmitter rated PEP. But how is this determined in the first place ? This question is discussed further in the experiment ***Amplifier overload***.

practical observation

You might be interested to look at both an SSB and a DSBSC signal when derived from speech. Use a SPEECH module. You can view these signals simultaneously since the DSBSC is available within the SSB generator.

Q *can you detect any difference,* ***in the time domain****, between an SSB and a DSBSC, each derived from (the same) speech ? If so, could you decide which was which if you could only see one of them ?*

TUTORIAL QUESTIONS

Q1 *what simple modification(s) to your model would change the output from the current to the opposite sideband ?*

Q2 *with a knowledge of the model configuration, and the individual module properties, determine analytically which sideband (USSB or LSSB) the model should generate. Check this against the measured result.*

Q3 *why are mass produced (and, consequently, affordable) 100 kHz SSB filters not available in the 1990s ?*

Q4 *what sort of phase error could the arrangement of Figure 4 detect ?*

Q5 *is the QPS an approximation to the Hilbert transformer ? Explain.*

Q6 *suggest a simple test circuit for checking QPS modules on the production line.*

Q7 *the phasing generator adds two DSBSC signals so phased that one pair of sidebands adds and the other subtracts. Show that, if the only error is one of phasing, due to the QPS, the worst-case ratio of wanted to unwanted sideband, is given by:*

$$SSR = 20\log_{10}[\cot(\frac{\alpha}{2})]dB$$

where α is the phase error of the QPS.

Typically the phase error would vary over the frequency range in an equi-ripple manner, so α would be the peak phase error.

Evaluate the SSR for the case α = 1 degree.

Q8 *obtain an expression for the* envelope *of an SSB signal (derived from a single tone message) when the only imperfection is a small amount of carrier 'leaking' through. HINT: refer to the definition of envelopes in the experiment entitled* ***Envelopes*** *in this Volume. At what ratio of sideband to carrier leak would you say the envelope was roughly sinusoidal ?* ***note****: expressions for the envelope of an SSB signal, for the general message m(t), involve the Hilbert transform, and the analytic signal.*

Q9 *sketch the output of an SSB transmitter, as seen in the time domain, when the message is two audio tones of equal amplitude. Discuss.*

Q10 *devise an application for the QPS not connected with SSB.*