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LB-878

A VESTIGIAL SIDEBAND FILTER

RADIO CORPORATION OF AMERICA

RCA LABORATORIES DIVISION

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Approved

Stuart Wm Seeley

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Introduction

Testing of television receivers is facilitated by a laboratory controlled signal source. A vestigial sideband filter used with a double sideband signal generator provides a test signal similar to a standard transmission.

The filter described in this bulletin is designed for use on Channel 6, with a video carrier frequency of 83.25 Mc. The impedance of the filter is 50 ohms. Both flexible cable and copper transmission lines are used in the construction, permitting an arrangement more compact than higher power commercial filters. The performance of the filter is substantially equivalent to commercially available transmitting type units, except for power handling capability. The total weight of the unit is 55 pounds and the dimensions are approximately 39 inches x 8 inches x 8 inches.

Theory of Operation

The function of this sideband filter* is to produce a vestigial sideband signal from a double sideband generator. A practical filter must have adequate fidelity of transmission within the pass band and a relatively constant input impedance.

Photographs of the filter described in this bulletin are shown in Figs. 1 and 2. A schematic diagram is given in Fig. 3. Lines A-B, C-D, E-F, and G-H in Fig. 3 are 50-ohm quarter-wavelength connecting lines. The Shunt Sections 1, 2, 3, and 4 are shorted half wavelengths at the frequencies indicated in the diagram. A graph of the reactance vs frequency characteristics of the shunt sections in the vicinity of their zero reactance frequencies is shown in Fig. 4. The reactance slope is the change in reactance per unit change in frequency. Sections 1 and 4 have a reactance slope of 14.25 ohms per megacycle and sections 2 and

*This filter design was conceived by Dr. George H. Brown and the first practical working model was developed by Mr. Donald W. Peterson of the David Sarnoff Research Center, RCA Laboratories Division.

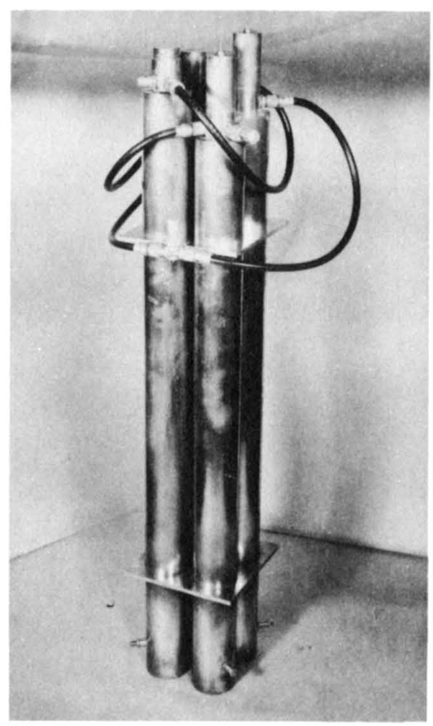


Fig. 1 - Front view of VSBF.

3, 21.5 ohms per megacycle. The capacitors at the input terminals to sections 3 and 4 (C_1, C_2) resonate with the inductive reactance of these sections at the carrier frequency (83.25 Mc). The inductors at the terminals of sections 1 and 2 (L_1, L_2) are resonant with the capacitive reactance of these sections at 81.5 Mc. One end of the filter is terminated in a 50-ohm dissipative resistor and the other end is terminated in a 50-ohm line or antenna.

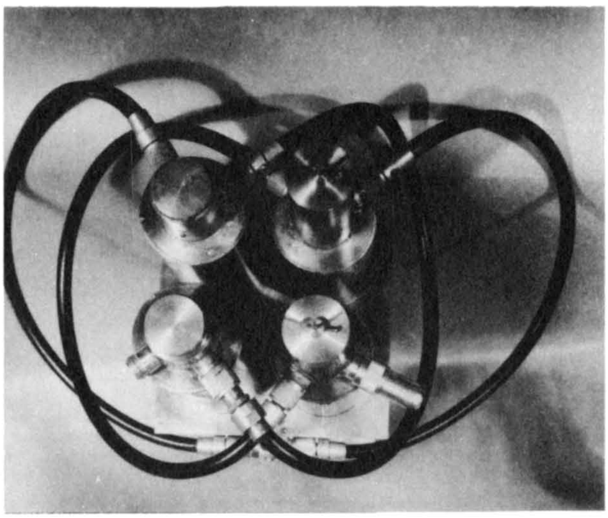


Fig. 2 - Top view of VSBF.

In the vicinity of the video carrier (83.25 Mc) the right half of the filter (Fig.3) represents a matched 50-ohm transmission line. The input impedance to the left half is very high due to the short circuit a quarter wavelength from the input terminals. The line losses are small so transmission efficiency to the load is high. These conditions are approximately true for frequencies up to the top of the channel. At 81.5 Mc the left half of the system is a matched 50-ohm transmission line and the input impedance to the right half is high. Thus, energy in the lower sideband is dissipated in the resistor while that in the upper sideband is transmitted to the load. In the crossover region (81.5 - 83.25 Mc) the sum of the input admittances is nearly constant.

The filter amplitude characteristic may be easily calculated with the following assumptions: the connecting sections remain 90 degrees electrical length, all reactive elements are lossless, the reactance-frequency characteristics of shunt sections 1, 2, 3, and 4 are

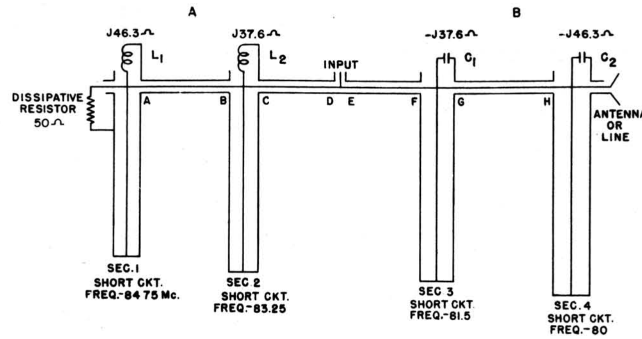


Fig. 3 - Schematic drawing of filter.

linear, and the lumped constants have constant reactance throughout the frequency band. Under these conditions

$$\frac{E_{antenna}}{E_{input}} = \frac{-1}{1 + (Y_F Y_H)/Y_o^2} \qquad (1)^*$$

where Y_F = admittance of elements at terminal F (Fig. 3)

Y_H = admittance of elements at terminal H

$Y_o = 1/Z_o = 0.02$ mho

The computed amplitude and phase characteristics are shown in Fig. 9.

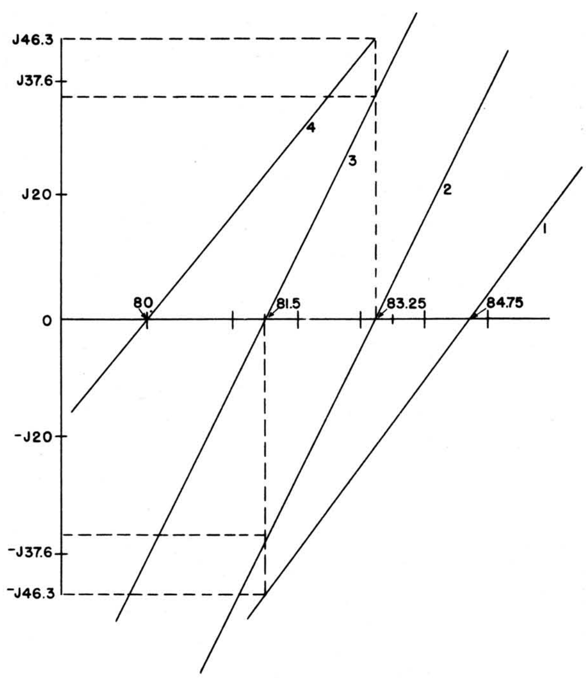


Fig. 4 - Reactance slopes of shunt sections.

*See Appendix for derivation of this equation.

Construction

The filter is constructed with copper lines for the shunt sections and with RG-8U cable in the connecting sections. To obtain the desired reactance slopes the shunt lines are made of two cascaded quarter-wave sections of different characteristic impedance. These quarter-wave sections are folded to conserve space as shown by Fig. 5. The reactance slope for this arrangement is given by:

$$\frac{dx}{df} \text{ in ohms per Mc} = \pi Z_1 \frac{[1+(Z_1/Z_2)]}{2f_o} \qquad (2)^*$$

f_o in megacycles

SECT.	SHORT CKT FREQ	A			B		C	
		I.D	O.D	LGTH	I.D	LGTH	O.D	LGTH
1	84.75 Mc.	1.37	1.50	34.4	2.5	33.9	.142	34.9
2	83.25	1.37	1.50	35.1	2.5	34.6	.0795	35.6
3	81.5	1.37	1.50	35.8	2.5	35.3	.0795	36.3
4	80	1 37	1.50	36.4	2.5	35 9	.142	36.9

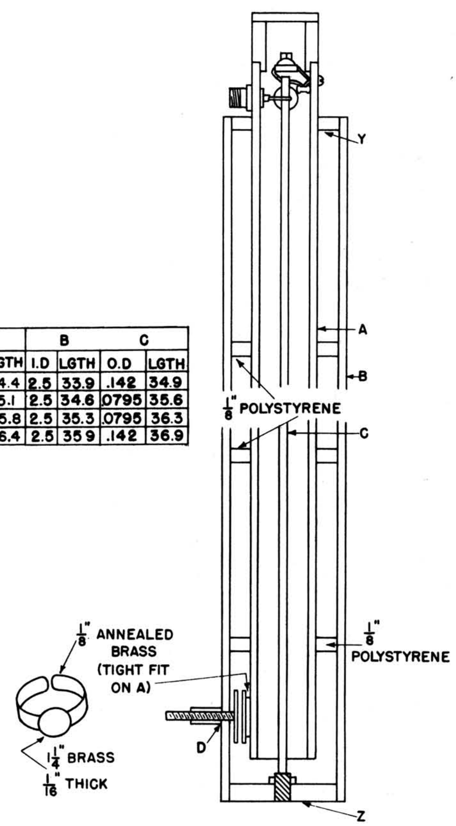


Fig. 5 - Cross sectional view of shunt lines.

In Fig. 5 Z_2 is the characteristic impedance between the inside diameter of conductor B and the outside diameter of conductor A. One end of this line is short circuited by brass disc Y. Z_1 is the characteristic impedance between the inside diameter of A and the outside diameter of C. The electrical length of these lines may be adjusted by a variable capacitor "D" located at the junction of the quarter-wave sections.

*See Appendix for derivation of this equation.

The connecting sections (RG-8U cable) are cut to a quarter wavelength at 83.25 Mc. This measurement includes a female connector at each end of the cable. Standard 50-ohm connectors are used to join the connecting sections to the shunt lines. Two connectors (90 degrees apart radially) are soldered into conductor A above the concentric shorting disc (Y in Fig. 5).

The resonating capacities for shunt sections 3 and 4 (C_1 and C_2 of Fig. 3) are mounted near the top of conductor B. The coils (L_1 and L_2 of Fig. 3) are mounted in a similar manner on shunt sections 1 and 2. They are wound with No.12 copper wire and have a Q of approximately 270 at 80 Mc. The diameter of the coils is 0.4 inch and the length 2½ inches. Details of the mounting are shown in Figs. 6 and 7.

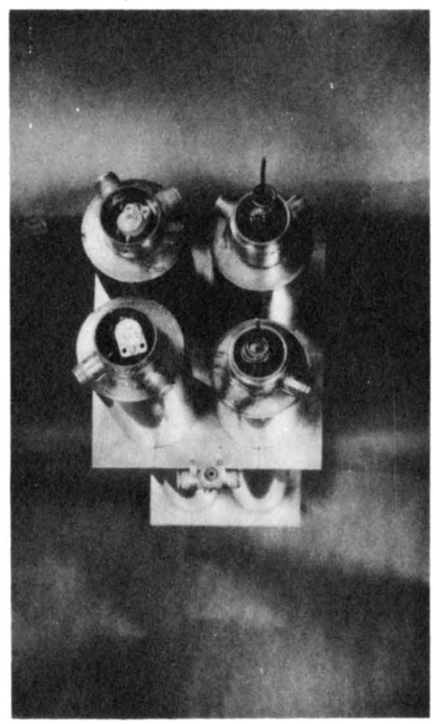


Fig. 7 - Top view of filter with shield caps removed.

The completed sections are held together by two brass clamping plates. This arrangement permits the filter to be mounted either horizontally or vertically. A T connector strapped to the upper brass plate is the input junction.

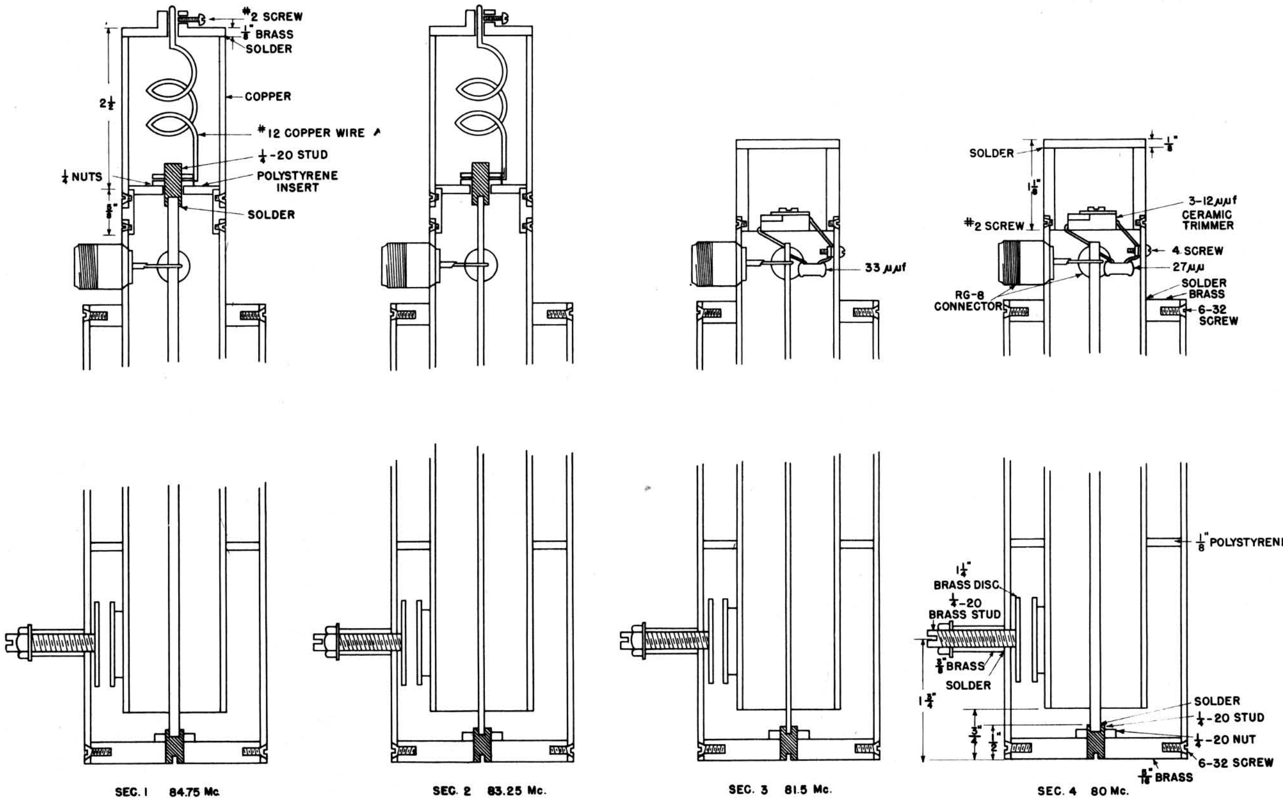


Fig. 6 - Details of shunt lines.

Alternative Choice of Conductor Sizes

The sizes of wire and tubing used in the construction of this filter are shown in the table in Fig. 5. Conductor B is 2.5 inches i.d. with 0.065 inch wall, conductor A is 1.5 inches o.d. with 0.065 inch wall. The material is hard round seamless copper tube. The calculated sizes for conductor C are 0.0795 inch and 0.142 inch. The standard sizes closest to this specification are 0.081 inch (B & S No. 12) and 0.148 inch (Stubs gauge No.9). The standard wire may be drawn to the correct size with a little tension. Alternative combinations of tubing size are listed in Table I.

Only one size (2½ inches i.d.) is shown for conductor B since the inside diameter is the only critical dimension and such tubing is generally available in a variety of wall thicknesses.

Table I

ALTERNATIVE CONDUCTOR SIZES		
CONDUCTOR B	CONDUCTOR A	CONDUCTOR C
(1) 2½" i.d.	1.5" o.d. - 0.083" wall	0.077" o.d. 0.138"
(2) 2½" i.d.	1.5" o.d. - 0.081" wall	0.077" 0.138"
(3) 2½" i.d.	1.5" o.d. - 0.049" wall	0.0815" 0.145"
(4) 2½" i.d.	1.5" o.d. - 0.028" wall	0.084" 0.150"
(5) 2½" i.d.	1.25" i.d. - 0.134" wall	0.072" 0.130"

Alignment

Two adjustments are necessary to place the filter in operation. First, adjust the electrical length of the shunt sections to a half wavelength at the proper short circuit frequencies. Connect a modulated signal generator to the input terminals of the filter. With a detector across the load terminals and the generator at a frequency of 80 Mc, set the voltage at the detector to a minimum by varying the capacitance of the air-trimmer capacitor on section 4 shown as D on Fig. 3. With the generator at 81.5 Mc make a similar adjustment upon shunt section 3. Then, place the detector across the dissipative resistor terminals and adjust shunt sections 1 and 2 to their respective short circuit frequencies by varying the capacitance of the air trimmer capacitors.

Adjustment of the lumped elements to resonance with the shunt sections is the next step in alignment. First, remove all connecting cables and the antenna and resistor. With a quarter-wavelength cable attached to section 4, apply a signal at the carrier frequency (83.25 Mc) to the end of the cable and detect the voltage at this point. Adjust the ceramic capacitor so that the detector voltage is a minimum. The minimum detector voltage is an indication of maximum impedance at the other end of the quarter-wavelength line. A similar adjustment is made upon section 3. For sections 1 and 2 the frequency of maximum impedance is 81.5 Mc and the adjustments are made by varying the inductances at the section terminals.

A final adjustment for optimum input voltage standing-wave ratio may be made with the filter connected for normal operation. This is done by placing an r-f sweep generator and a detector in parallel at the filter input terminals. The detected sweep voltage is an indication of the input impedance of the filter. The lumped elements are slightly readjusted so that the variations in input impedance are a minimum. The test setup for the final adjustment is shown in Fig. 8.

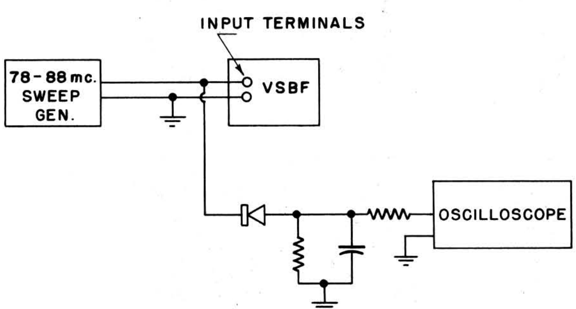


Fig. 8 – Final alignment setup.

Results

Measurements of the performance of the filter are shown in Figs. 9 and 10. Fig. 9 compares the measured phase and amplitude characteristics with those calculated by use of Eq. (1). The measured standing-wave ratio is plotted in Fig. 10.

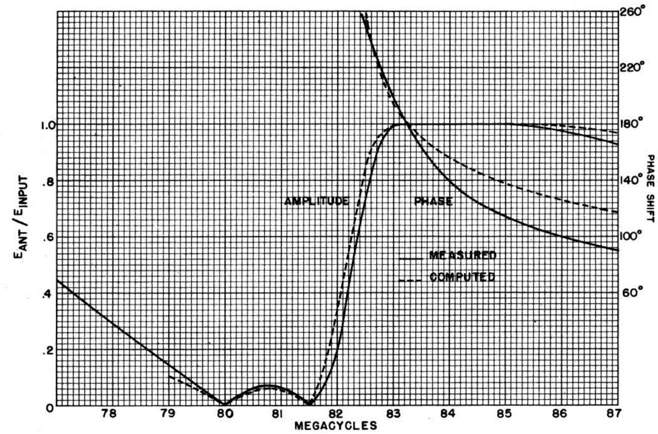


Fig. 9 – Amplitude and phase characteristic.

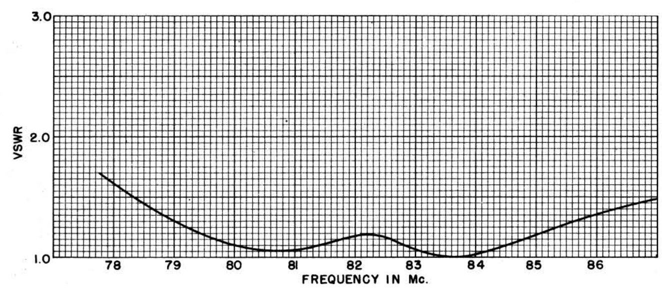


Fig. 10 – Standing wave ratio.

Phase Correction

Phase distortion of the frequency spectrum in the vicinity of the carrier is introduced by the sideband filter. A plot of this variation of time delay with frequency is shown in Fig. 11. Adequate compensation for this dis-

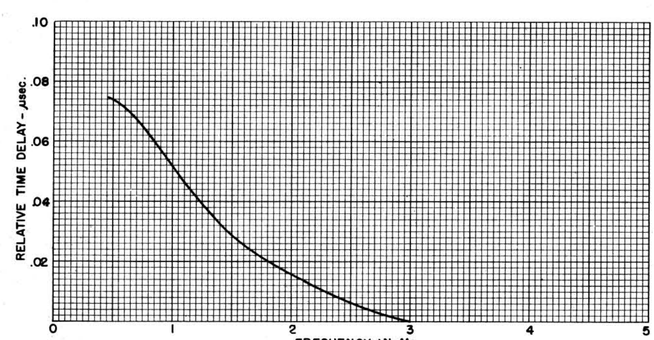
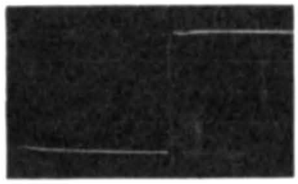
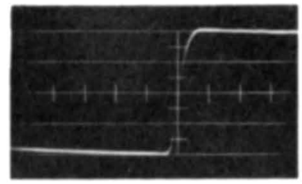
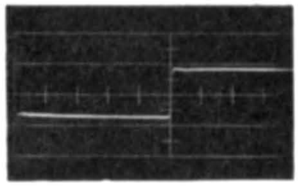
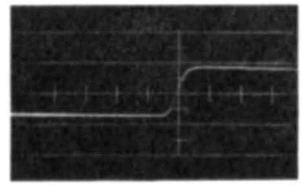
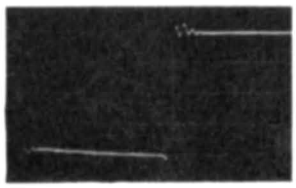
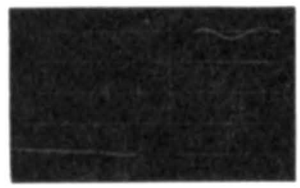
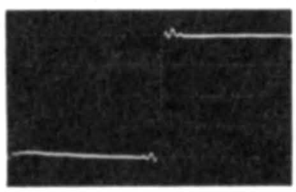
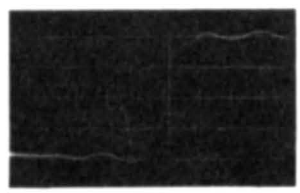
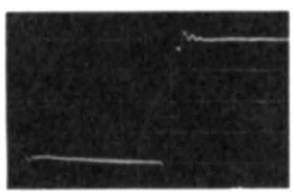
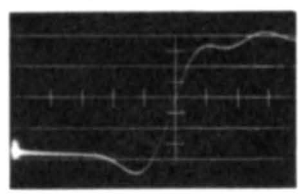
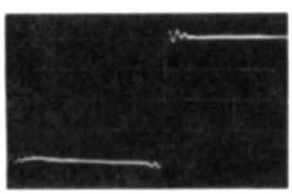
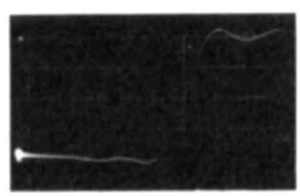
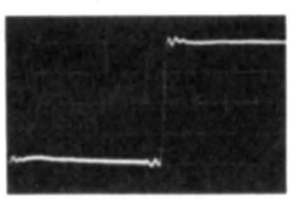
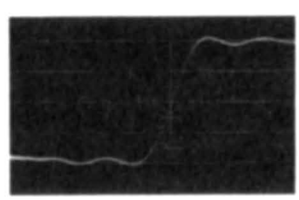


Fig. 11 – VSBF delay distortion.

Horizontal Scale	1 µsec/division	0.1 µsec/division
Fig. 14 – Input square wave.		
Fig. 15 – Signal generator output.		
Fig. 16 – Receiver re sponse to uncompensated double side band signal.		
Fig. 17 – Receiver re- sponse to compensated double side band signal.		
Fig. 18 – Receiver re- sponse to vestigial side band signal.		
Fig. 19 – Receiver re- sponse to vestigial side band signal with com- pensation for side band filter.		
Fig. 20 – Receiver response to vestigial side band signal with full compensation.		

ortion may be obtained through the use of a bridged-T network located in the video section of the transmitter.[1] The network used for compensation of this filter is indicated in Fig. 12.

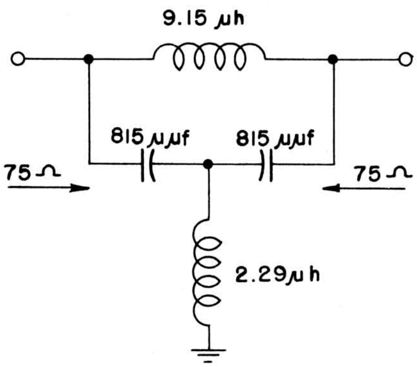


Fig. 12 - Phase compensation network for VSBF.

The time delay characteristic of the compensating network is shown in Fig. 13. There is some variation in time delay in the correction network above 3 Mc. This is not required for compensation of the sideband filter, but it partially corrects for the distortion associated with i-f cutoff in television receivers.[2]

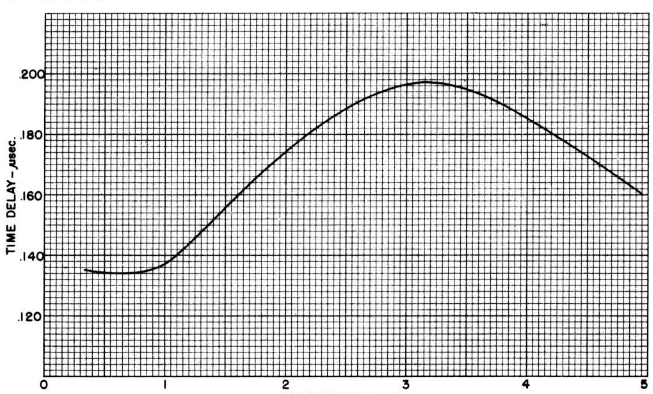


Fig. 13 - Time delay characteristic of VSBF phase compensation network.

A series of photographs is presented in Figs. 14 through 20 to illustrate the effect of the sideband filter upon a television system. The data were obtained from a test setup using a double sideband signal generator, the filter described in this bulletin, a television receiver, and suitable correction networks. The video signal was a 100-kc square wave and the modulation of the signal generator was about 50 per cent. Each condition was photographed on two different time axes to show both the overall pattern and details of the variations in the neighborhood of the transition. Fig. 14 shows the waveform at the video input to the system and Fig. 15 is a view of the square wave detected at the signal generator r-f output terminals. The response of the test receiver to a double sideband signal is shown in Fig. 16 and the effect of compensation for i-f cutoff in a double sideband system is demonstrated in the next set of pictures, Fig. 17. Addition of the sideband filter to the system produces the pattern of Fig. 18. The phase distortion is very evident at the beginning of the transition. If the transition is from black to white the distortion appears on the kinescope as a leading black; if the transition is from white to black the distortion is a leading white. The effect of adding the correction network shown in Fig. 12 to the system is illustrated by Fig. 19. The result of the high-frequency compensation added by this correction network is evident from the near symmetry of the transition. The receiver response to a fully compensated vestigial sideband signal is shown in Fig. 20. Comparison of Figs. 17 and 20 shows that transmission through the compensated vestigial sideband system is essentially identical with double sideband transmission.

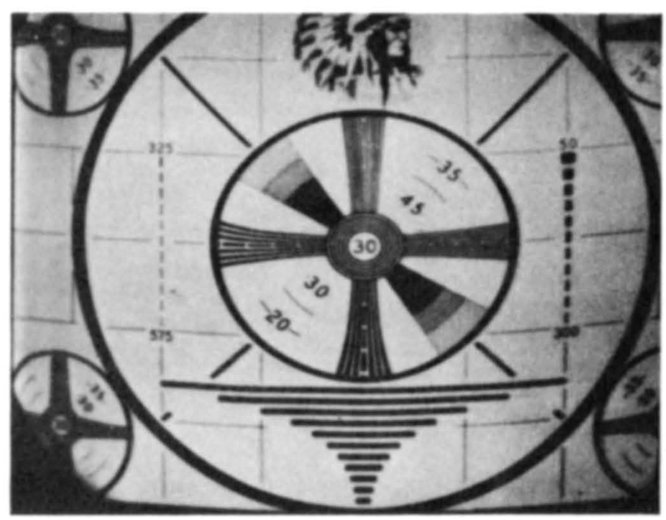


Fig. 21 - Test pattern transmitted through VSB system.

A photograph of a test pattern transmitted through the compensated vestigial sideband system is shown in Fig. 21.

John B. Merrill
John B. Merrill

[1] R. D. Kell and G. L. Fredendall, "Standardization of the Transient Response of Television Transmitters", *RCA Review*, Vol. 10, p. 17, 1949.
[2] ibid.

Appendix

Derivation of Eq. (1):

For a quarter-wave lossless line, the input and output voltages are related by:

$$\frac{E_{out}}{E_{in}} = -j\,\frac{Y_o}{Y_R} \qquad (3)$$

where Y_o is the characteristic admittance of the line $(1/Z_o)$ and Y_R is the admittance terminating the line.

The input admittance to a quarter-wave lossless line is given by:

$$Y_{in} = \frac{Y_o^2}{Y_R} \qquad (4)$$

For two cascaded quarter-wave sections with lumped elements at the junctions (Fig. 3):

$$\frac{E_{antenna}}{E_{input}} = \frac{E_{antenna}}{E_F} \times \frac{E_F}{E_{input}} = -j(Y_o/Y_H) \times -jY_o/[Y_F + (Y_o^2/Y_H)] \qquad (5)$$

$$\frac{E_{antenna}}{E_{input}} = -\frac{1}{[1+(Y_F Y_H/Y_o^2)]}$$

Y_H = admittance of elements at terminal H (Fig. 3)

$$Y_H = \frac{1}{50} + \frac{j}{46.3} + \frac{1}{j(f-80)14.25} \qquad (6)$$

Y_F = admittance of elements at terminal F

$$Y_F = \frac{j}{37.6} + \frac{1}{j(f-81.5)21.5} \qquad (7)$$

Derivation of Eq. (2):

The reactance of a lossless short-circuited line is given by:

$$X_{sc} = jZ_2 \tan\theta \qquad (8)$$

where Z_2 is the characteristic impedance and θ is the electrical length of the line.

If another section of line with a different characteristic impedance is added in series, the input impedance of the system is

$$X_{in} = \frac{jZ_1(Z_1+Z_2)\cot\theta}{Z_1\cot^2\theta} \qquad (9)$$

$$\text{if } \theta = \frac{\pi}{2}\frac{f}{f_o} \text{ then:} \qquad (10)$$

$$\frac{dx}{df} = \frac{j\pi Z_1(Z_1+Z_2)/2f_o \cdot (\cot\pi f/2f_o)/\sin^2(\pi f/2f_o)}{[Z_1\cot^2(\pi f/2f_o)-Z_2]^2} - \frac{[j\pi Z_1(Z_1+Z_2)]/2f_o}{Z_1\cos^2(\pi f/2f_o)-Z_2\sin^2(\pi f/2f_o)} \qquad (11)$$

for $f = f_o$:

$$\frac{dx}{df} = j\pi\frac{Z_1[1+(Z_1/Z_2)]}{2f_o}$$