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FREQUENCY REJECTION FILTER FOR USE IN DC RESISTIVITY SURVEYS

(Report and 6 text figures)

L. S. Collett and R. H. Ahrens

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ABSTRACT

The design procedure is given for calculating the components of a rejection filter at any frequency, which takes into account the source impedance and load resistance. The values of two filters have been calculated for a maximum attenuation at 0.5 cps and 60 cps.

The DC insertion loss is 2% for the 0.5 cps filter with a voltage rejection ratio of 28:1. The DC insertion loss is 1% for the 60 cps filter with a voltage rejection ratio of 200:1. Recent field trials showed that the 0.5 cps filter reduced the interference by 50 to 75%.

FREQUENCY REJECTION FILTER FOR USE IN DC RESISTIVITY SURVEYS

INTRODUCTION

Interference from 60 cycles and surges are often encountered when using the DC resistivity method near power transmission lines and industrial machinery. Because of these J.E. Wyder, of the Geological Survey of Canada, was unable to obtain reliable readings when measuring low-level DC potentials near the Steelman-Frobisher oil fields in southern Saskatchewan. A slowly varying interference with a period of approximately 2 seconds (0.5 cps) was superimposed on the DC readings. It is not known whether this interference signal is a slowly varying DC potential in the ground or a 0.5 cps surge that modulates the 60 cps power line interference.

With this scanty information, two rejection filters were designed using a twin-T RC network. One filter was designed to have maximum attenuation at 0.5 cps and the other at 60 cps.

FILTER PARAMETERS

The twin-T RC network, which has a maximum attenuation characteristic at one frequency, has two properties that are suitable for this application, namely, low insertion loss for DC potentials and high impedance at DC. Oono[1] has developed equations that take into account any source resistance, r_1, and any load resistance, r_2, in the design of the filter (see Fig. 1). The following equations are used in designing the filter. The equation numbers refer to those in Oono's paper.

$$R = xr_1 \qquad (14)$$

$$C = \frac{u}{2\pi f_o R} \qquad (4)$$

$$R_1 = kR, \quad C_1 = \frac{C}{k} \qquad (2)$$

$$R_2 = \frac{Rk}{u^2(1+k)}, \quad C_2 = C\,\frac{(1+k)}{u^2 k} \qquad (3)$$

[1]Oono, Yosiro: Design of parallel-T resistance-capacitance networks; Proc. IRE, vol. 43, No. 5, pp. 617-619, 1955.

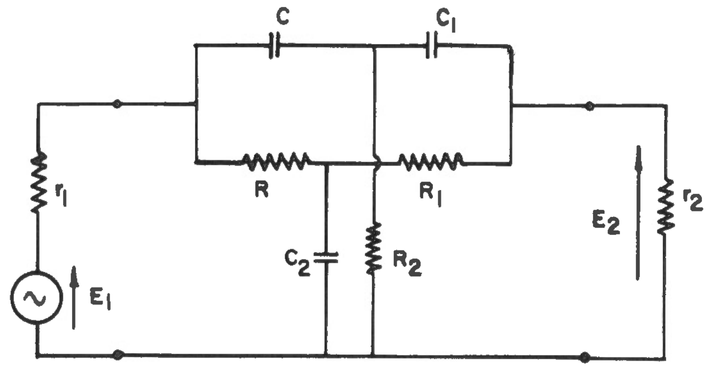

FIGURE 1 TWIN-T RC network

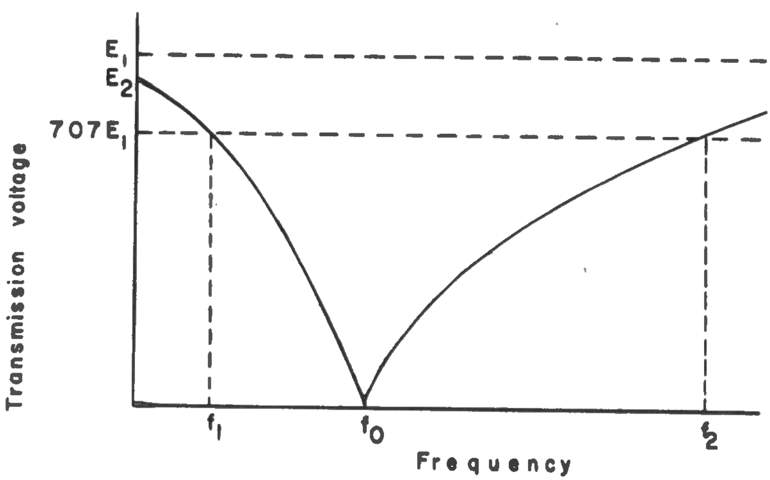

FIGURE 2 Attenuation characteristic curve

where r_1, r_2, R, R_1, R_2, C, C_1, and C_2 represent the components as shown in Figure 1 and f_o = frequency at greatest attenuation;

also

$$x = \alpha / \beta \tag{32}$$

$$k = \gamma / \alpha \tag{33}$$

$$u = \sqrt{n\,k\,x^2 - 1} \tag{34}$$

$$\left.\begin{aligned}
\alpha &= M^2 - 2nM + (1-n)^2 \\
&= 2n\,\frac{\Delta^2 + 4}{\Delta^2 - 4} + 4\sqrt{n}\,\frac{\Delta}{\sqrt{\Delta^2 - 4}} + 2 \\
\beta &= M(1+n) - (1-n)^2 \\
&= 4n + 2\sqrt{n}\,(1+n)\,\frac{\Delta}{\sqrt{\Delta^2 - 4}} \\
\gamma &= \frac{1}{n}\left[M^2 - 2M + (1-n)^2\right] \\
&= 2\,\left(\frac{\Delta^2 + 4}{\Delta^2 - 4}\right) + 4\sqrt{n}\,\frac{\Delta}{\sqrt{\Delta^2 - 4}} + 2n
\end{aligned}\right\} \tag{35}$$

where M represents the loss at the extreme frequencies, f_1 and f_2, for which

$$M = \frac{E_1}{\sqrt{2}\,E_2} \tag{21}$$

$$\Delta = \frac{f_2 - f_1}{f_o} \tag{23}$$

(see Fig. 2 for the meaning of the symbols),

and

$$n = r_1 / r_2. \tag{13}$$

Restrictions on M and Δ are that

$$M > (1 + \sqrt{n})^2 \qquad (28)$$

and

$$\Delta > 2 \qquad (24)$$

The minimum value of M for a prescribed Δ (>2) is obtained from the equation

$$M = 1 + n + 2\sqrt{n} \; \frac{\Delta}{\sqrt{\Delta^2 - 4}} \qquad (31)$$

DESIGN PROCEDURE

The value for Δ was arbitrarily chosen equal to 2.3. With r_1 = 100 ohms and $r_2 = 10^7$ ohms, $n = \frac{r_1}{r_2} = 10^{-5}$. From (31), M = 1.01281, which meets the restriction on M (see equation (28)).

Substituting M = 1.01281 and $n = 10^{-5}$ in equations (35)

α = 2.025743
β = 0.012840
γ = 14.325570

Substituting the values for α, β, and γ in equations (32), (33), and (34)

x = 158.0
k = 7.060
u = 0.875

Substituting the values for x, k, and u in equations (14), (4), (2) and (3), the parameters for the twin-T filter for 0.5 cps and 60 cps are derived and listed in Table I.

Table I

Component Values for 0.5 cps and 60 cps Twin-T Filter

f_o	0.5 cps	60 cps
R, ohms	15.8 k	15.8 k
R_1, ohms	111.4 k	111.4 k
R_2, ohms	18.1 k	18.1 k
C, uf	17.65	0.147
C_1, uf	2.5	0.02
C_2, uf	26.35	0.219

In addition to these filter parameters, a 10-megohm resistor is wired in across the filter output to maintain a constant load, r_2.

MEASUREMENT OF FILTER CHARACTERISTICS

A Keithley electrometer voltmeter Model 600A is used to measure the attenuation and impedance characteristics of the filter. The high input electrometer impedance of 10^{14} ohms shunted by 30 picofarads does not load the high filter impedance ($\approx$10 megohm). The electrometer is also used as an amplifier, which has a frequency response from DC to 100 cycles on the most sensitive range, rising to 1,000 cps on the least sensitive range. The output impedance of the electrometer is 17 k ohms. Thus, the electrometer can be used as an impedance transfer device from high ohmic to comparatively low ohmic impedances. Then voltage-measuring test instruments with moderately high input impedances can be used to measure the voltage at the output of the electrometer amplifier.

The apparatus used to measure the attenuation characteristic of the twin-T filter is shown on Figure 3. For the DC potential source, a battery was used and for low frequencies a Servomex Low Frequency Waveform Generator Model LF.51 supplied the signal. A resistor of 2.2 k ohms is placed across the output of the generator to maintain a constant voltage signal over all frequencies into the filter. The output impedance is 100 k ohms for the Moseléy Model 680 recorder, 2 megohms for the Analab Oscilloscope Model 1120-R with Model 700 plug-in unit, and 10 megohms for the Hewlett-Packard Voltmeter Model 400D.

The apparatus used to measure the impedance characteristic of the twin-T filter is shown on Figure 4. A variable resistor, R_n, was inserted in series with the input to the twin-T filter. The ratio

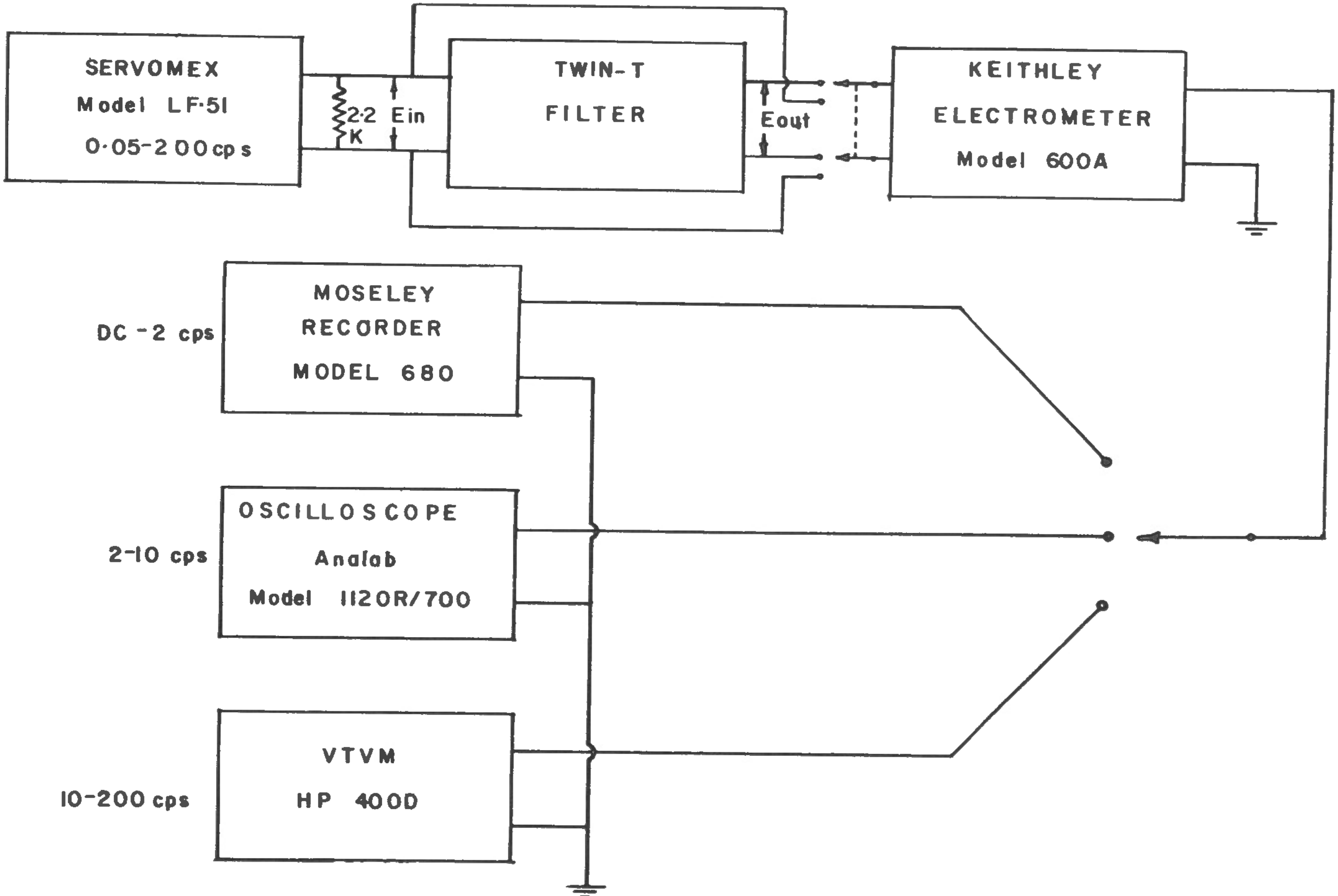

FIGURE 3 **Method used to measure attenuation characteristic of TWIN-T filter**

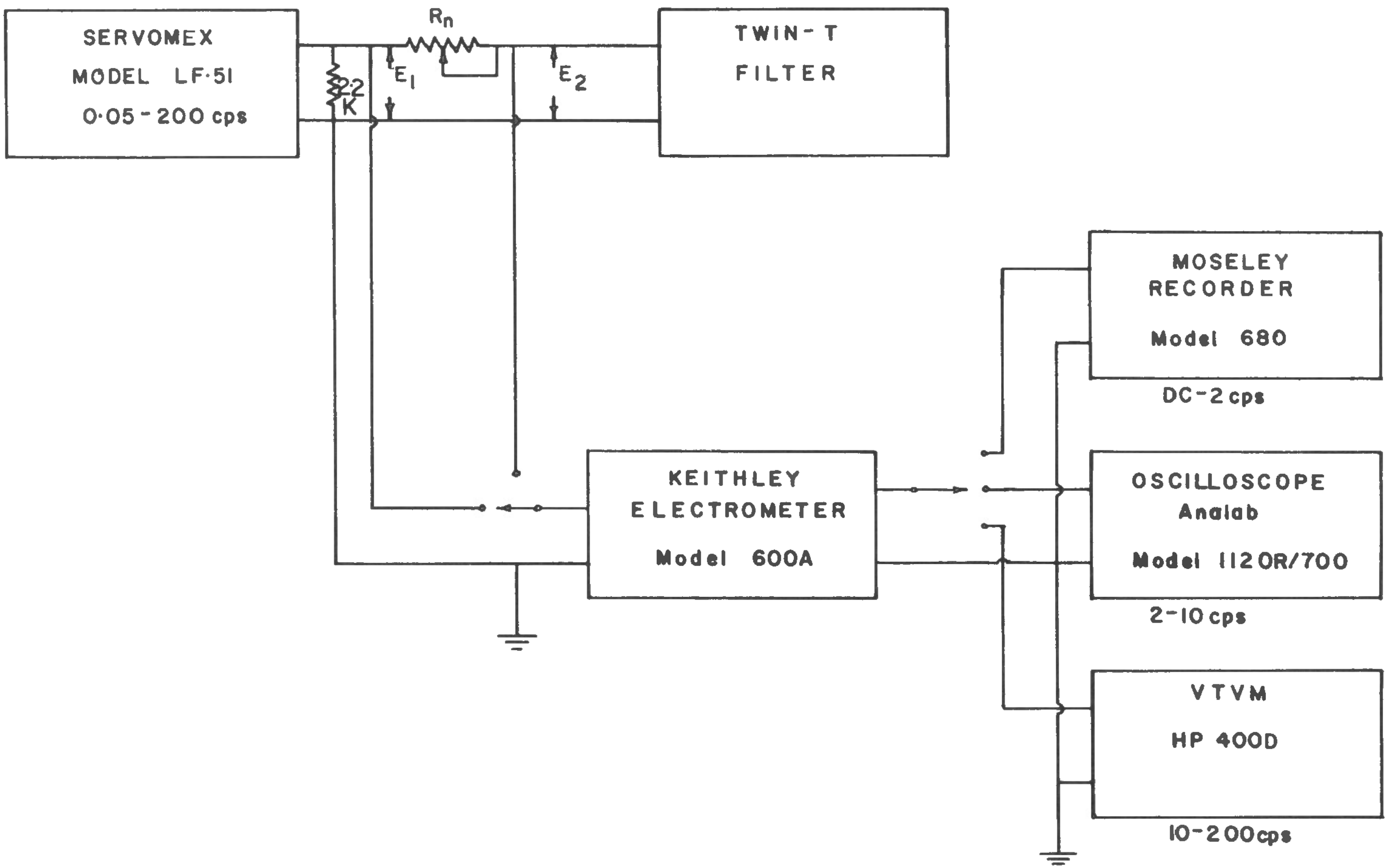

FIGURE 4 Method used to measure impedance characteristic of TWIN-T filter

of the voltage applied across the resistor R_n in series with the impedance of the filter, R_{in}, to the voltage across the filter impedance is given by the equation

$$\frac{E_1}{E_2} = \frac{R_n + R_{in}}{R_{in}}$$

$$R_{in}\left(\frac{E_1}{E_2} - 1 = R_n\right)$$

$$R_{in} = \frac{R_n}{\left(\frac{E_1}{E_2} - 1\right)}$$

If $E_1 = 2E_2$, then $R_{in} = R_n$.

The test instruments used and the frequencies covered are the same as used in the attenuation measurements.

RESULTS

The attenuation and impedance characteristics of the 0.5 cps and 60 cps twin-T filters are shown on Figures 5 and 6 respectively. For the 0.5 cps filter, the insertion loss at DC is 2% and the rejection ratio at 0.5 cps is 28:1. The impedance of the filter is 3.3 megohm at DC, dropping to 1,600 ohms at 60 cps. For the 60 cps filter, the insertion loss at DC is 1% and the rejection ratio at 60 cps is 200:1. The impedance of the filter is 10 megohm at DC, dropping rapidly to 9,500 ohms at 200 cps.

CONCLUSION

The 0.5 cps and 60 cps rejection filters have been tried out in the Steelman-Frobisher oil fields by J.E. Wyder. The 60 cps filter had no effect on the low frequency noise interference. The 0.5 cps filter did remove 50 to 75% of the low frequency noise. The amount of interference that was removed varied with the rate at which the oil pumps work. The assumption that the low frequency noise interference is modulated 60 cps is not correct. An analysis of the noise signal in the ground will have to be done to establish more precisely the frequency content of the interference.

Construction and measurements on the filters were done by W.J. Stauffer and some of the drafting of the figures was done by D.A. Clark.

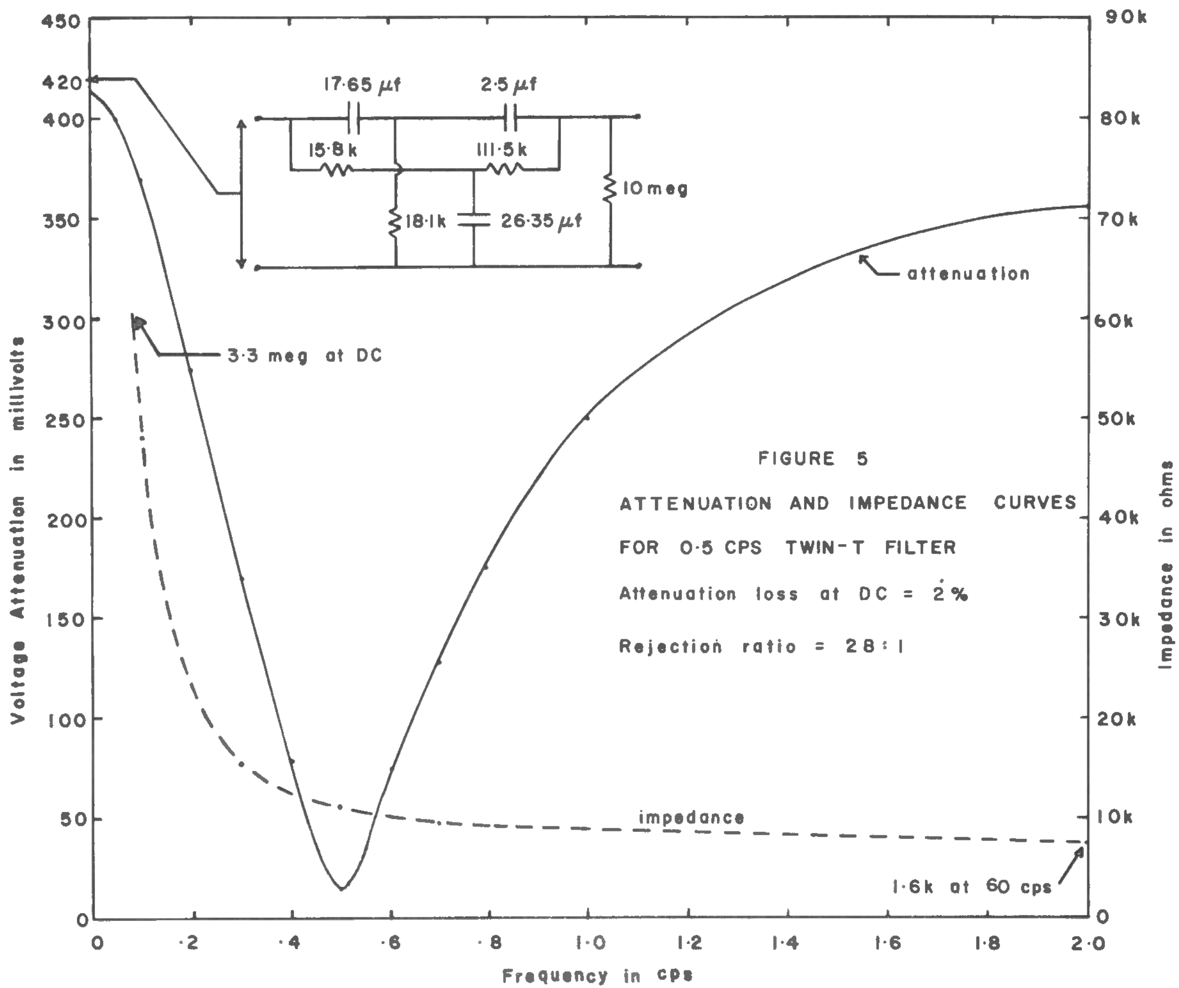

FIGURE 5

ATTENUATION AND IMPEDANCE CURVES

FOR 0·5 CPS TWIN-T FILTER

Attenuation loss at DC = 2%

Rejection ratio = 28:1

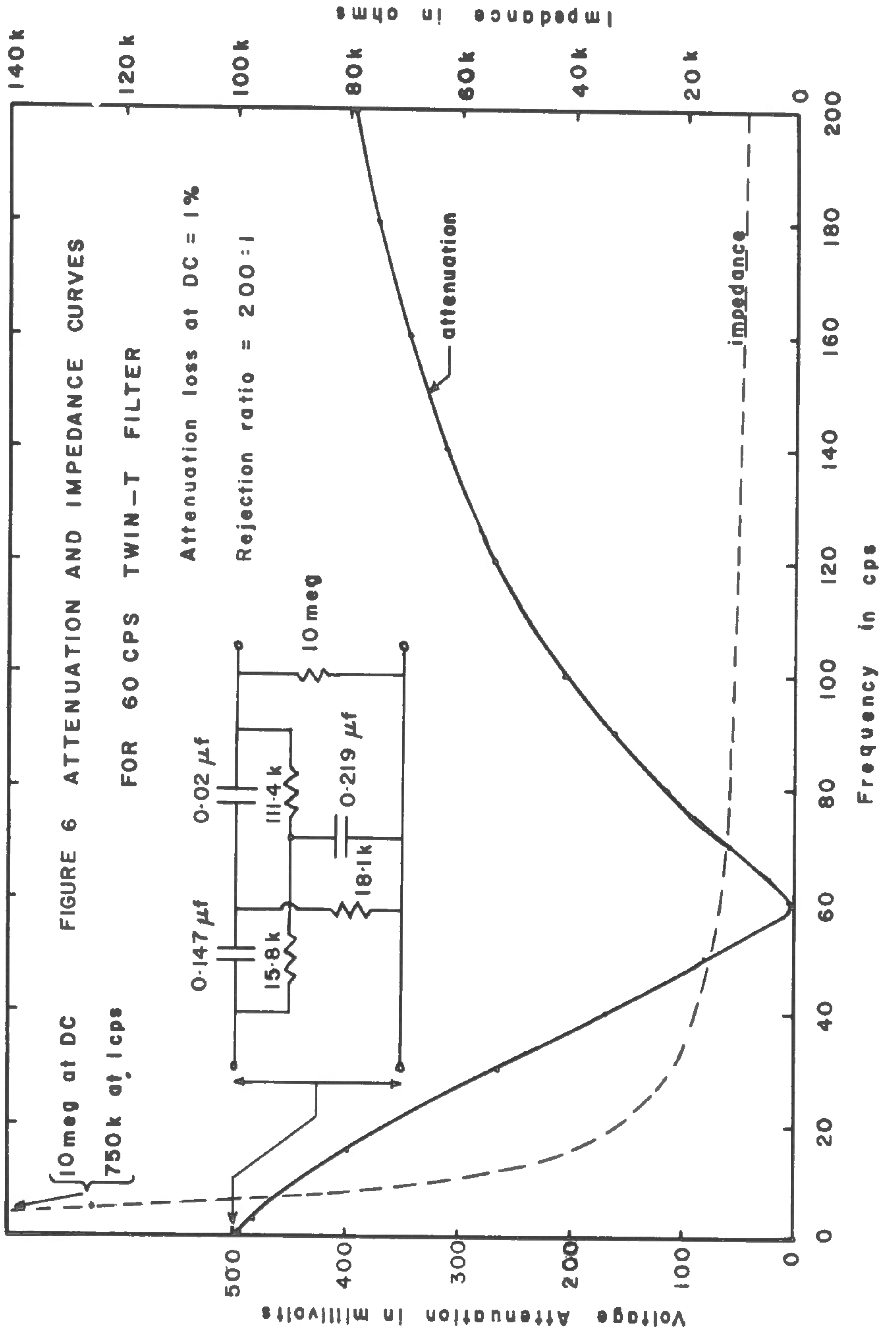

FIGURE 6 ATTENUATION AND IMPEDANCE CURVES FOR 60 CPS TWIN-T FILTER

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