AMPLITUDE, PHASE, AND TIME DELAY CHARACTERISTICS
FOR THE R390/URR AM RECEIVER

Technical Memorandum No. 38

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ABSTRACT

Amplitude, phase and time delay characteristics for the R390/URR receiver operating in its various IF bandwidth modes are presented. These characteristics have been determined from test results. Testing methods and procedures are outlined. A short discussion on the meaning of the time delay characteristics as applied to jamming susceptibility tests is included. Based on the test results and the operating characteristics of a General Electronics type jamming susceptibility measuring system it is concluded that the time delay through the R390/URR receiver will have negligible effect on the results of a General Electronics type jamming susceptibility test on the R390/URR. It is expected that these receiver characteristics will be used in setting up and interpreting further EDG tests on the R390/URR.
AMPLITUDE, PHASE, AND TIME DELAY CHARACTERISTICS

FOR THE R390/URR AM RECEIVER

I. INTRODUCTION

General Electronics Laboratories, Inc. of Cambridge, Massachusetts has developed two observerless systems to measure speech intelligibility through a communications channel. The systems are described in Reference 1. The Electronic Defense Group is interested in employing a similar system to evaluate jamming susceptibility of communications receivers. The basic block diagram of one General Electronics system is shown in Figure.

FIG. 1

GENERAL ELECTRONICS INTELLIGIBILITY MEASURING DEVICE
The General Electronics system is essentially a correlation scheme which measures discrepancies between the desired speech signal and the corrupted signal that is actually received. With no jamming, the test setup is adjusted to produce a minimum output from the comparator. Noise or distortion through the system under test will produce non-cancelling components of signal at the input to the comparator, which will, in turn, produce an indication of reduced intelligibility on the meter. The relative importance of the component of meter indication due to phase distortion through the system under test will be considered in this memorandum.

Phase shift through the system under test can take two forms: a phase distortion component and a linear phase shift component. Each of these phase shift components produces a non-cancelling component of signal at the comparator. Phase distortion constitutes a reduction of intelligibility. Therefore, the effect of phase distortion should be included in the indication of reduced intelligibility. Linear phase shift (i.e., phase shift proportional to frequency) does not reduce intelligibility. Linear phase shift gives rise to time delay that is a measure of the transit time or time required to transmit a signal through the system. Therefore, the non-cancelling component of signal into the comparator that is due to linear phase shift should not be included in the indication of reduced intelligibility.

The results of transfer function tests conducted on the R390/URR AM receiver are presented in (1) the form of curves of amplitude response, (2) phase shift and time delay versus frequency. It is expected that these curves will be useful in subsequent jamming susceptibility testing of the R390/URR receiver. Receiver characteristics for the R390/URR are tabulated in Appendix C.
II. TEST PROCEDURE

2.1 Test Setup

A block diagram of the test setup appears in Figure 2.

An audio oscillator and a Hewlett-Packard Model 608A signal generator were used to generate a 12 mc AM test signal for the R390/URR receiver. The audio output of the receiver was compared to the audio oscillator signal for amplitude ratio and phase shift versus frequency to determine the transfer function of the signal generator and receiver combination. A discussion of the method used to measure phase shift employing a bullseye template overlay on the CRO face is presented in Appendix A.

The instruction manual for the Model 608A Signal Generator states that the allowable modulating frequency range is 20 cps to 100K cps. The manual does not specify regulation of output modulation versus modulation frequency or describe the modulation transfer function. As a check on modulation transfer function a constant amplitude modulating signal was slowly varied in frequency from 20 cps to 20K cps. Observation of the output level meter and the percent modulation meter
on the signal generator indicated no significant change in signal level or percent modulation in this range. It is assumed that if the modulator amplitude characteristic is flat the phase shift of modulation envelope with respect to modulating signal will be negligibly small. Reference 1 and other reports referenced therein indicate that the lowest audio frequency of interest for intelligibility score tests is on the order of 100 cps. It is assumed that the data obtained from this test setup are independent of signal generator over the frequency range 100 cps to 20K cps.

Data for amplitude ratio and phase shift vs audio frequency were taken for various combinations of IF bandwidth, audio filtering, and receiver detuning. For each case, receiver RF gain and audio gain were adjusted to produce the best apparent signal-to-noise ratio and the best apparent linearity (i.e., least distortion of the audio output signal). For each case 50% modulation was employed. The carrier signal strength was adjusted to produce 60 db indication on the receiver carrier level meter corresponding to approximately 200 μ volts at the receiver input. All of this testing was conducted with the receiver on AGC function at the medium setting.

2.2 Tuning Method

As a standard receiver tuning method, the modulation was reduced to zero, the receiver was operated on the 0.1 Kc IF bandwidth mode and tuned for maximum indication on the carrier level meter. This tuning dial setting was used as center tuning for all positions of the IF bandwidth selector switch in the subsequent tests. This tuning procedure was carried out immediately preceding and following each set of test data readings. The difference in tuning before and after each test was used as a measure of receiver or signal generator drift during the test. In several cases the drift was deemed unacceptable and the test was repeated. Typical values of receiver drift for the data considered acceptable were on the order of .3 to .5 Kc with 12 mc nominal carrier frequency. Subsequent testing
indicates that for the above tuning procedure the error (i.e., the deviation of IF frequency from the center of the IF passband) in IF frequency (nominally 455 Kc) is \(-0.5 \pm 0.05 \text{ Kc}\).

2.3 Receiver Drift

The R390/URR receiver apparently requires a warmup period of approximately 2 hours for good tuning stability. After 5 minutes warmup tuning drift with nominal 12 mc carrier is approximately 20 Kc/min. After 30 minutes warmup tuning drift is approximately 1 Kc/min. To establish whether this drift was occurring in the signal generator or in the receiver the signal generator was turned on and allowed a 2 hour warmup. The receiver was then turned on and during receiver warmup approximately the same drift characteristic was noted, indicating that the receiver is responsible for most of the drift noted above.

2.4 Transfer Function Testing

For the case of wide and medium audio response transfer function data were taken for the 16 Kc, 8 Kc, 4 Kc and 2 Kc IF bandwidth modes. In the other narrower IF bandwidth modes harmonic distortion of the audio output restricted the accuracy and meaning of data taken by this method. Testing was discontinued on the assumption that transfer function data for these narrow IF bandwidth modes would be of limited value or interest. The curves obtained are presented in Figures 3 to 10.

In an attempt to determine the effect of detuning on receiver transfer function two sets of data for the 16 Kc IF bandwidth mode were obtained. For these curves the receiver was detuned \(\pm 5 \text{ Kc}\) from the nominal 12 mc carrier. Similar tests for the 4 Kc IF bandwidth mode with detuning \(\pm 2 \text{ Kc}\) from the nominal 12 mc carrier were attempted. For the \(\pm 2 \text{ Kc}\) detuning case data were obtained although large second and third harmonic distortion components make the data questionable. For the \(-2 \text{ Kc}\) detuning case severe harmonic distortion
NOTE: SCALE FACTOR CHANGE BY FACTOR OF 50 AT ZERO TIME DELAY

Fig. 3. R390/URR RECEIVER RESPONSE TEST
16 Kc IF Bandwidth
Wide Band Audio
Note: Scale factor change by factor of 50 at zero time delay.

Fig. 4. R390 URR Receiver Response Test
8 Kc IF Bandwidth
Wide Band Audio
**Note:** Scale factor change by factor of 10 at zero time delay.

**Fig. 6.** R390/URR Receiver Response Test
- 2 Kc IF Bandwidth
- Wide Band Audio
NOTE: SCALE FACTOR CHANGE BY FACTOR OF 25 AT ZERO TIME DELAY

FIG. 7. R390/URR RECEIVER RESPONSE TEST
16 Kc IF Bandwidth
Medium Audio Response
NOTE: SCALE FACTOR CHANGE BY FACTOR OF 25 AT ZERO TIME DELAY

FIG. 8. R390/URR RECEIVER RESPONSE TEST
8 Kc IF Bandwidth
Medium Audio Response
NOTE: SCALE FACTOR CHANGE BY FACTOR OF 10 AT ZERO TIME DELAY

FIG. 9. R390/URR RECEIVER RESPONSE TEST
4 Kc IF Bandwidth
Medium Audio Response
NOTE: SCALE FACTOR CHANGE
BY FACTOR OF 10 AT
ZERO TIME DELAY

FIG. 10, R390/URR RECEIVER RESPONSE TEST
2 Kc IF Bandwidth
Medium Audio Response
NOTE: SCALE FACTOR CHANGE BY FACTOR OF 50 AT ZERO TIME DELAY

FIG. 11. R900/UNR RECEIVER RESPONSE TEST
16 Kc IF Bandwidth
Wide Band Audio
Receiver Detuned - 5 Kc Below 12 mc Carrier

FIG. 11
FIG. 12.  UR50/URR RECEIVER RESPONSE TEST
16 Kc IF Bandwidth
Wide Band Audio
Receiver Detuned 5 Kc Above 12 mc Carrier

NOTE: SCALE FACTOR CHANGE
BY FACTOR OF 50 AT
ZERO TIME DELAY
rendered data meaningless. Data for receiver detuning are presented in the curves of Figures 11 and 12.

2.5 IF Bandpass

The IF bandpass characteristic was measured to determine the degree of symmetry around the IF center frequency. Asymmetry of the IF bandpass characteristic was checked as a possible explanation for the difference in harmonic distortion observed for detuning above and below carrier frequency. A curve of the IF bandpass with amplitude ratio plotted on db scale is presented in Figure 13. To expand the curve and give better indication of the shape around center frequency, the IF bandpass characteristic with amplitude ratio plotted as a numeric is presented in Figure 14.

A block diagram of the test setup for determining the IF bandpass characteristics appears in Figure 15.
Fig. 14. R390/URR Receiver IF Bandpass Characteristic
To determine the IF bandpass characteristic a 12 mc cw carrier from the 608A signal generator was fed into the R390/URR receiver, the receiver tuning was varied and the undetected IF output amplitude and frequency were measured. The shape of the plot of this data for IF output amplitude vs IF frequency is the shape of the IF bandpass characteristic. These tests were conducted on manual gain function. For the 16 Kc bandwidth mode the test was repeated at two RF gain settings to check for possible effect of RF gain on the shape of the IF bandpass characteristic. RF gain also controls the gain of two IF amplifier stages. The effect of RF gain was found to be negligible. Data for IF bandwidth characteristics were obtained for the 16 Kc, 8 Kc and 4 Kc bandwidth modes.

III. DISCUSSION OF RESULTS

3.1 Time Delay Characteristics

For each of the transfer function curves time delay, expressed by the following equation, is plotted.

$$\tau = \frac{\phi}{\omega}$$

$$\tau = \text{time delay in seconds}$$

$$\phi = \text{phase shift in radians}$$

$$\omega = \text{frequency in radians/sec.}$$

Time delay here is the shift in time of the audio waveform as it passes through the signal generator-receiver combination. The positive time delay noted on the curves may be startling if thought of as meaning the output happens before the input but the idea of positive time delay is a logical consequence of and means the same thing as the concept of positive phase shift or phase lead through a network.

Another definition for time delay commonly seen takes a derivative form:

$$\tau_m = \frac{d\phi}{d\omega}$$
This is envelope time delay, the delay of an amplitude modulation envelope through a network, related to group velocity, whereas the $\tau$ above is related to phase velocity (Reference 2). A discussion of the meaning of $\tau$ and $\tau_m$ is presented in Appendix B.

To determine jamming susceptibility of an RF link by employing the General Electronics device, the RF link can be thought of as a black box with a transfer function for the speech signal and a transfer function for the jamming signal. No particular restrictions are necessary on these transfer functions except that the system under test must be operating in a realistic mode to produce useful information concerning jamming susceptibility. The RF link is operating as a black box with an audio input and audio output. Therefore, the time delay expression of interest here is $\tau = \phi/\omega$ as plotted on the transfer function curves in Section 3.2. These curves of time delay versus frequency indicate that the time delay can be thought of as a time shift or transit time component plus a delay distortion component. Each of the curves of time delay vs frequency approaches a constant straight-line value at the high frequency end of the audio spectrum above 1 Kc. This is the time shift component and could logically be subtracted out to leave the delay distortion component. Because the time delay characteristic approaches a straight-line time shift component, the phase characteristic could logically be decomposed into a linear phase shift component ($\phi_1 = \tau_2 \omega$) plus a phase distortion component ($\phi_2 = f(\omega)$). The point here is that this linear plus distortion phase characteristic should be considered in setting up a General Electronics type jamming susceptibility test for a receiver. As described in General Electronics reports their system does not differentiate between linear phase shift and phase distortion. As described in the introduction, linear phase shift does not reduce intelligibility. Therefore, the effect of linear phase shift should not be included in the intelligibility score.
The General Electronics system compares two envelopes of a narrow band of audio signal scanned out of a wide band audio signal by the heterodyne action of the scanning filters. The scanning filter is about 100 cps wide and slowly scans the audio frequency range. With detection occurring after the filter the resultant frequency components of the signal into the comparator are roughly only as high as 50 cps (analogous to the detected audio from a double sideband amplitude modulated carrier with sidebands ± 50 cps wide about the carrier). Therefore, the shortest period corresponding to the highest frequency components of signal into the comparator will be a period of 20 milliseconds. The average period of frequency components in the comparator is about 40 milliseconds. Thus, any delays introduced by the system under test must be small compared to 40 milliseconds.

The test results presented in the curves of this memorandum indicate time delay on the order of 4 to 20 milliseconds in the frequency range 100 to 40 cps, delay less than 4 milliseconds from 100 to 200 cps, and delay less than 1 millisecond above 200 cps. As mentioned in Section 2.1 the lowest audio frequency of interest for intelligibility measurements is on the order of 100 cps. Over the audio frequency range of interest time delay through the R390/URR is small compared to 40 milliseconds and therefore should have negligible effect on the intelligibility score for jamming susceptibility tests conducted with the General Electronics system.

3.2 Transfer Function Characteristics

Comparison of the experimental curves of this memorandum and the response curves presented in the Instruction Book for Radio Receiver R-390/URR indicates good correspondence. The overall audio response chart of the instruction book presents curves for wide and medium audio filter. These correspond to the 16 Kc IF bandwidth, wide band audio curve (see Figure 3), and the 16 Kc IF bandwidth, medium audio response curve (see Figure 7). The test
curves agree closely with the curves of the instruction manual.

3.3 IF Response Characteristics

The IF response chart of the instruction manual indicates that the IF bandwidth positions are rather loosely labeled. On the basis of 6 db down in amplitude ratio as a criterion for bandwidth, the 16 Kc, 4 Kc and 2 Kc curves are approximately 16 Kc, 4 Kc and 2 Kc wide, respectively, but the 8 Kc bandwidth curve indicates actual bandwidth of approximately 10 Kc. The test curves for IF bandwidth presented in Figures 13 and 14 agree closely with the curves of the instruction manual. The test curves for IF bandwidth do not indicate any apparent assymetry that would account for the distortion encountered when attempts were made to measure overall audio response for the case of receiver detuning. However, relatively minor variations in the shape of the IF bandwidth characteristic could produce the distortion effects noted. To determine these minor variations would require greater precision and more extensive testing. It is felt that more extensive testing to determine the sources of distortion for the case of receiver detuning is beyond the scope and interest of this memorandum.

IV. CONCLUSIONS

The curves presented herein are of sufficient scope and accuracy to be of interest in setting up subsequent jamming susceptibility tests for the R390/URR receiver.

It seems apparent that observerless test schemes for measuring jamming susceptibility require careful, detailed mathematical analysis to thoroughly understand the meaning and significance of the quantities being measured.
The presence of major distortion effects under conditions of minor receiver detuning could lead to misinterpretation of intelligibility measurements. These distortion effects were noted on the R390/URR receiver operating in IF bandwidth modes below 8 Kc.
APPENDIX A

TEST METHOD FOR PHASE MEASUREMENT

A quick and convenient method for determining phase shift in the audio and sub-audio frequency range with accuracy on the order of $\pm 3^\circ$ is commonly employed in the field of servo mechanisms and automatic control. This method employs a bullseye template pattern on the face of a CRO. The calibrated bullseye pattern permits direct reading of phase shift from a Lissajous scope pattern. For accuracy and convenience the bullseye pattern is a significant improvement over the method of measuring the X and Y intercepts of the Lissajous pattern and computing phase shift by a trigonometric function. In the presence of harmonic distortion, where the transfer function for the equivalent fundamental component is of interest, the bullseye pattern is particularly useful because it facilitates interpolation of the fundamental component phase shift out of a distorted Lissajous pattern.

Consider a voltage $e_x \sin \omega t$ applied to the scope X-axis and a voltage $e_y \sin (\omega t + \phi)$ applied to the scope Y-axis. Consider also the resultant Lissajous phase pattern with X and Y gain adjusted to fit the phase pattern into a tangent square two units on a side.

![Diagram of Lissajous pattern with labels for X and Y axes, 10 units on a side.]

FIG. A.1
Consider a circle of radius \( r \) inscribed in the Lissajous phase pattern and tangent to the phase pattern.

At time \( t \):

\[
x = \sin \omega t
\]

\[
y = \sin (\omega t + \phi)
\]

\[
f(t) = \sin \omega t + j \sin (\omega t + \phi) = x + jy
\]

where \( f(t) \) describes the location of the spot on the scope face.

At time \( t_1 \):

\[
|x| = |y|
\]

\[
|x|^2 + |y|^2 = r^2
\]

- \( \sin \omega t_1 = \sin (\omega t_1 + \phi) \)

The minus sign here is required to give absolute value of \( x \) because at time \( t_1 \), \( x \) is negative. Equation A.4 could also be written \(-x = y\) at time \( t_1 \).

- \( \sin \omega t_1 = \sin \omega t_1 \cos \phi + \cos \omega t_1 \sin \phi \)

- \( 1 = \cos \phi + \frac{\cos \omega t_1}{\sin \omega t_1} \sin \phi \)

- \( \cot \omega t_1 = -\frac{1 + \cos \phi}{\sin \phi} \)

\[
\tan \omega t_1 = -\tan \frac{\phi}{2} = \tan \left(-\frac{\phi}{2}\right)
\]

\[
\omega t_1 = -\frac{\phi}{2}
\]

\[
r = \sqrt{\sin^2 \omega t_1 + \sin^2 (\omega t_1 + \phi)}
\]

\[
r = \sqrt{\sin^2 \frac{\phi}{2} + \sin^2 \frac{\phi}{2}}
\]

\[
r = \sqrt{2} \sin \frac{\phi}{2}
\]

There remains a problem of ambiguity since phase shifts in multiples of \( \frac{\pi}{2} \) produce Lissajous phase patterns having the same shape. This problem of recognition of the phase pattern orientation which corresponds to zero phase
<table>
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<th>$r$</th>
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<td>90°</td>
<td>1.000</td>
</tr>
<tr>
<td>80°</td>
<td>0.908</td>
</tr>
<tr>
<td>70°</td>
<td>0.810</td>
</tr>
<tr>
<td>60°</td>
<td>0.707</td>
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<td>50°</td>
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</tr>
<tr>
<td>10°</td>
<td>0.123</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
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</table>

$r = \sqrt{2} \sin \frac{\phi}{2}$

**FIG. A.2**
shift and determination of the zero phase shift frequency from the several frequencies for which the network under test has phase shift of \(2\pi\) can usually be resolved through some \textit{a priori} knowledge of the operation of the network, the network amplitude characteristic and the relation between amplitude and phase characteristics for the network.
APPENDIX B

DEFINITION OF TIME DELAY

Two expressions for time delay, $\tau = \frac{\phi}{\omega}$ and $\tau_m = \frac{d\phi}{d\omega}$, are commonly encountered in technical literature. A simple analysis will illustrate the meaning of each of these expressions and demonstrate the reason for using $\tau = \frac{\phi}{\omega}$ to express time delay for the curves of this memorandum.

Consider a network with transfer function and input as defined by Figure B.1 and the equations below:

\[ G(\omega) = H(\omega) e^{j\phi(\omega)} \]  
\[ E_1 = A(1 + m \cos \omega_1 t) \cos \omega_0 t \quad \text{for} \quad \omega_0 > \omega_1 \quad m < l \]  
\[ (B.1) \]
\[ \text{FIG. B.1} \]

In general, Eq B.2 is a linear transfer function that expresses gain and phase shift for each frequency component of signal through the network.

The interest here is in phase shift and resultant time delay. Therefore, consider the special case $H(\omega) = 1$ and $A = 1$.

Then:

\[ G(\omega) = e^{j\phi(\omega)} \]  
\[ (B.3) \]
\[ E_1 = \cos \omega_0 t + m \cos \omega_1 t \cos \omega_0 t \]  
\[ = \cos \omega_0 t + \frac{m}{2} \cos (\omega_0 + \omega_1) t + \frac{m}{2} \cos (\omega_0 - \omega_1) t \]  
\[ (B.4) \]
\[ = \text{Re} \left\{ e^{j\omega_0 t} + \frac{m}{2} e^{j(\omega_0 + \omega_1) t} + \frac{m}{2} e^{j(\omega_0 - \omega_1) t} \right\} \]  
\[ (B.5) \]

The input signal, as usual, can be decomposed into three components; one at carrier frequency and two at the sum and difference frequencies. The
transfer function, $e^{j\varphi(\omega)}$, must be defined for each of these component signals. The interest here is in the time delay of the carrier and the modulation envelope passing through the network. The time delay of the carrier component illustrates the case of time delay for any simple sinusoid through a linear network. Interest in time delay of the modulation envelope implies interest in distortionless transmission. The shape of the modulation envelope must be preserved in transmission through the network or envelope time delay would have no meaning. For distortionless transmission each of the sideband components must be phase shifted through the same phase angle, $\Delta \varphi$.

Then:

$$G(\omega_0) = e^{j\varphi(\omega_0)} \quad (B.7)$$

$$G(\omega_0 + \omega_1) = e^{j[\varphi(\omega_0) + \Delta \varphi]} \quad (B.8)$$

$$G(\omega_0 - \omega_1) = e^{j[\varphi(\omega_0) - \Delta \varphi]} \quad (B.9)$$

These expressions define a phase characteristic which has odd symmetry about the carrier frequency $\omega_0$.

$$E_0 = G(\omega) E_1 \quad (B.10)$$

$$E_0 = G(\omega) \text{Re} \left\{ e^{j\omega_0 t} + \frac{m}{2} e^{j(\omega_0 + \omega_1) t} + \frac{m}{2} e^{j(\omega_0 - \omega_1) t} \right\} \quad (B.11)$$

$$= \text{Re} \left\{ e^{j\omega_0 t} \cdot e^{j\varphi(\omega_0)} + \frac{m}{2} e^{j(\omega_0 + \omega_1) t} \cdot e^{j[\varphi(\omega_0) + \Delta \varphi]} + \frac{m}{2} e^{j(\omega_0 - \omega_1) t} \cdot e^{j[\varphi(\omega_0) - \Delta \varphi]} \right\} \quad (B.12)$$
\[
E_0 = \Re \left\{ e^{j[\omega_0 t + \phi(\omega_0)]} + \frac{m}{2} e^{j[(\omega_0 + \omega_1) t + \phi(\omega_0) + \Delta \phi]} + \frac{m}{2} e^{j[(\omega_0 - \omega_1) t + \phi(\omega_0) - \Delta \phi]} \right\}
\]
\[\text{(B.13)}\]

\[
= \Re \left\{ e^{j[\omega_0 t + \phi(\omega_0)]} + m e^{j[\omega_0 t + \phi(\omega_0)]} \left( \frac{e^{j[\omega_1 t + \Delta \phi]} + e^{-j[\omega_1 t + \Delta \phi]}}{2} \right) \right\}
\]
\[\text{(B.14)}\]

\[
= \Re \left\{ e^{j[\omega_0 t + \phi(\omega_0)]} + m \cos (\omega_1 t + \Delta \phi) e^{j[\omega_0 t + \phi(\omega_0)]} \right\}
\]
\[\text{(B.15)}\]

\[
= \cos [\omega_0 t + \phi(\omega_0)] + m \cos (\omega_1 t + \Delta \phi) \cos [\omega_0 t + \phi(\omega_0)]
\]
\[\text{(B.16)}\]

\[
\therefore E_0 = \left[1 + m \cos (\omega_1 t + \Delta \phi)\right] \cos [\omega_0 t + \phi(\omega_0)]
\]
\[\text{(B.17)}\]

This expression for output has the same form as the original amplitude modulation input expression and includes carrier phase shift and modulation envelope phase shift (Reference 3). Factoring out \(\omega_0\) and \(\omega_1\) this equation illustrates two forms of time delay.

\[
E_0 = \left[1 + m \cos \omega_1 (t + \frac{\Delta \phi}{\omega_1})\right] \cos \omega_0 \left[t + \frac{\phi(\omega_0)}{\omega_0}\right]
\]
\[\text{(B.18)}\]

\[
E_0 = \left[1 + m \cos \omega_1 (t + \tau_m)\right] \cos \omega_0 \left(t + \tau_o\right)
\]
\[\text{(B.19)}\]

where:

\[
\tau_o = \frac{\phi(\omega_0)}{\omega_0} = \text{delay of the carrier}
\]
\[\text{(B.20)}\]

This corresponds to the general expression for time delay of a simple sinusoid through a linear network.

\[
\tau = \frac{\phi}{\omega}
\]
\[\text{(B.21)}\]

\(\tau = \text{time delay in seconds}\)

\(\phi = \text{phase shift in radians}\)

\(\omega = \text{frequency in radians/second}\)
and where:

\[ \tau_m = \frac{\Delta \phi}{\Delta \omega} = \text{delay of the modulation envelope} \]  

(B.22)

This corresponds to the general expression for time delay of a simple sinusoidal modulation envelope through a distortionless transmission.

\[ \tau_m = \frac{\Delta \phi}{\Delta \omega} \]  

(B.23)

\[ \tau_m = \text{modulation envelope time delay in seconds} \]

\[ \Delta \phi = \text{difference in phase shift for carrier and upper and lower sidebands in radians} \]

\[ \Delta \omega = \omega_0 - (\omega_0 - \omega_1) = (\omega_0 + \omega_1) - \omega_0 \]

= Deviation of sideband frequency from carrier frequency.

Distortionless transmission of a simple sinusoidal modulation envelope requires only that the network amplitude characteristic have even symmetry about \( \omega_0 \) and the network phase characteristic have odd symmetry about \( \omega_0 \).

**FIG. B.2; EVEN SYMMETRY AMPLITUDE CHARACTERISTIC**

**FIG. B.3; ODD SYMMETRY PHASE CHARACTERISTICS**

Distortionless transmission of a complex modulation envelope is more restrictive. This requires flat amplitude characteristic and linear phase characteristic throughout the sideband frequency spectrum. For this case \( \phi(\omega) = \pm k(\omega - \omega_0) + \phi(\omega_0) \) throughout the sideband spectrum.
Then:

\[
\frac{\Delta \phi}{\Delta \omega} = \pm k = \frac{d\phi(\omega)}{d\omega} \quad (B.24)
\]

This gives rise to the expression for envelope time delay commonly seen in the literature.

\[
\tau_m = \frac{\Delta \phi}{\Delta \omega} = \frac{d\phi}{d\omega} \quad (B.25)
\]
APPENDIX C

R-390/URR RECEIVER CHARACTERISTICS

Type of Circuit. Triple-conversion superheterodyne on eight lowest-frequency bands; double-conversion superheterodyne on all other bands.

Frequency Range. 5 to 32 mc (in 32 steps).

Types of Signals Received. A1 - cw, A2 - mcw, A3 - voice, F1 - frequency shift keying.

Type of Tuning. Continuous; frequency read directly on counter-type indicator.

Method of Calibration. Built-in crystal-controlled calibration oscillator, calibrated at increments of 100 kc.

IF Selectivity. 100 cps to 16 kc bandwidth in 6 steps.

IF Frequencies. First: 9 to 18 mc
           Second: 2 to 3 mc
           Third: 455 kc

Sensitivity. AM signals: 3 µv
            CW signals: 1 µv

Number of Tubes. 33

Weight. 80 lbs.
REFERENCES


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