SAE Aerospace
An SAE International Group

AEROSPACE RECOMMENDED PRACTICE

SAE ARP1267

Issued 1973-08
Reaffirmed 2013-02

Electromagnetic Interference Measurement Impulse Generators; Standard Calibration Requirements and Techniques

RATIONALE

ARP1267 has been reaffirmed to comply with the SAE five-year review policy.

1. SCOPE

1.1 This Aerospace Recommended Practice (ARP) describes a standard method and means for measuring or calibrating the "Spectrum Amplitude" output of an impulse generator.

1.2 This ARP also outlines the method for the measurement of EMI instruments impulse bandwidth.

2. REFERENCED DOCUMENTS

2.1 IEEE 3rd Draft of "Proposed Standard for the Measurement of Impulse Strength and Impulse Bandwidth," IEEE Subcommittee 27.1, dated February 1973, Subcommittee Chairman, Dr. R. M. Showers.

2.2 Patent No. 3,736,504, "Broadband Spectral Intensity Measurement System," Co-inventors, Frank K. Koide and Fred R. Hume.

3. REQUIREMENTS

3.1 Impulse Generators: An impulse generator is a device which is capable of producing narrow periodic pulses of such shape and duration that they contain an energy component known as spectrum amplitude to very high frequencies. In operation, a d-c voltage is used to charge a calibrated coaxial transmission line. The pulses are produced when the line is discharged in its terminating impedance through mechanically vibrating contacts, and approaches an ideal impulse. These mechanical contacts consist of either vibrating diaphragm or mercury wetted relay switches and in certain cases magnetic relay switches. By proper choice of transmission line length and resistive termination, it is possible to produce periodic transients or impulses having relatively uniform frequency spectrum to a predetermined frequency. More recently, all solid-state impulse generators without mechanical contacts have been produced.

The output of the impulse generator consists of a d-c pulse train similar to the one shown in Figure 1. The frequency spectrum of the pulse train is shown in Figure 2. The frequency spectrum of the pulse can be determined from the Fourier analysis. The spectrum consists of a d-c component and a number of frequency components. By means of the Fourier analysis one can show that the amplitude of the spectrum goes to zero at a frequency corresponding to $1/\tau$ (see Figure 2). A practical impulse generator therefore, which has a pulse width of 0.5 ns will have zero output at a frequency of $1/\tau = 1/0.5 \times 10^{-9}$ S or 2 GHz.

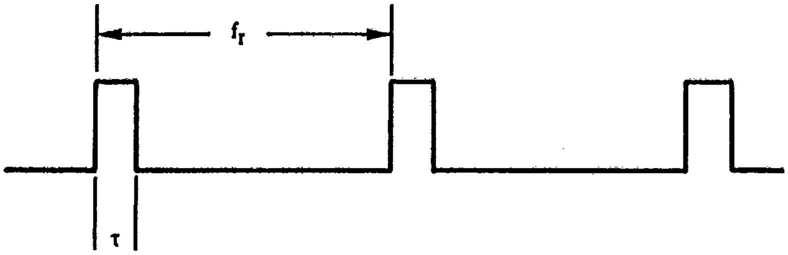


Figure 1. Impulse Generator Output Pulse Train

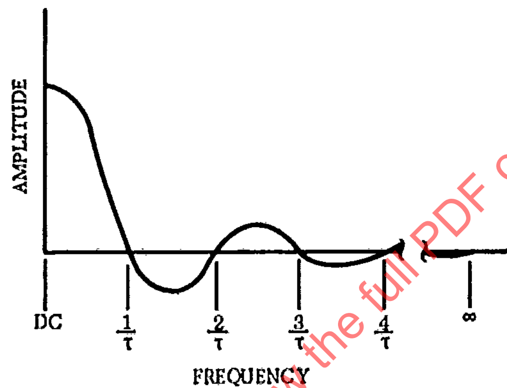


Figure 2. Pulse Train Frequency Spectrum

The spectrum amplitude of an impulse is determined from the pulse area.

$$S = 2A_I \qquad (1)$$

Where S = spectrum amplitude in volts per hertz bandwidth.

A_I = pulse area in volt-second.

The output spectrum amplitude specification of most commercially available impulse generators are stated in units of rms microvolts per megahertz bandwidth or decibels above one rms microvolt per megahertz bandwidth, abbreviated, dB/μ V/MHz.

Theoretically there is no limit to the upper frequency for which an impulse generator can be designed, however, there are practical difficulties which tend to restrict the frequency range for an impulse generator using a mechanical switch. It becomes increasingly difficult to build a switch into the center conductor as the transmission line becomes smaller.

Another consideration is that the performance of the impulse generator is degraded to some extent by reflections resulting from imperfections in the construction of the transmission line and the output circuit. The performance also degrades as a function of time due to corrosion and electroplating of the contacts on the electromechanical switch which alternately charges and discharges the transmission line.

These factors make the calibration of the spectrum amplitude output of the impulse generator a necessity.

The impulse generators are used for the calibration of the peak or broadband sensitivity of the EMI field intensity meter. The accuracy of the field intensity meter is primarily determined by the accuracy of the calibration of the impulse generator. In many cases the impulse generator is an integral part of the field intensity meter. As a combination it is readily available for field use as well as in the laboratory.

3.2 Spectrum Amplitude: The technique is based in the comparison of the spectrum amplitude of the impulse generator to the spectrum amplitude of a known broadband signal.

The broadband signal is developed by pulse modulating a CW signal. By accurately measuring the amplitude of the CW signal and the pulse width, the spectrum amplitude, over bandwidths which are small compared to the reciprocal of the pulse width, may be calculated.

The calibration of the spectrum amplitude output of an impulse generator by this standard, does not require the knowledge of the impulse bandwidth of a receiver. The receiver is only used as an indicator to compare the spectrum amplitude of the impulse generator to the spectrum amplitude of a pulse modulated CW signal. The only requirement of the receiver used as an indicator is that it has sufficient sensitivity and bandwidth to perform the measurement.

The spectrum of the impulse generator is modified by the receiver bandpass in the same manner as the spectrum of the pulsed modulated CW signal. The output of the pulse modulated CW signal is adjusted to give the same peak output of the receiver as the impulse generator, and the spectrum amplitude of the impulse generator can be determined from the amplitude and pulse width of the pulsed CW signal.

Mathematical analysis of this method is contained in the attached Appendix A.

3.3 Impulse Bandwidth: The measurement of impulse bandwidth can be obtained from the voltage ratio of the pulse modulated CW signal to the CW signal multiplied by the reciprocal of the pulse width.

This measurement process can be shown from EQ (A-9) (in the appendix).

$$S = E\tau_o$$

Where E is the CW voltage indication of the receiver or field intensity meter (FIM). τ_o is the pulse width, modulating the CW signal source. S is the spectrum amplitude in volts/hertz.

Since the impulse bandwidth is proportional to the level of the spectrum amplitude, the following equation can be given as:

$$E_r = S\, I_{BW} \tag{2}$$

Where E_r is the pulse modulated CW signal indication on the receiver or FIM.

I_{BW} is the impulse bandwidth on the receiver or FIM.

Combining Eq (9) and (2) leads to the resulting equation:

$$I_{BW}\ (\text{hertz}) = \frac{E_r\ (\text{volts})}{E\ (\text{volts})} \cdot \frac{1}{\tau_o\ (\text{seconds})} \tag{3}$$

E_r/E is a ratio which can be measured by noting the change in amplitude on the receiver or FIM under CW and pulse modulated condition. In practice, the impulse bandwidth I_{BW} can be measured by the change in attenuation in decibels (dB) and then converted to a voltage ratio for solution of Eq (3).

An alternate method in measuring the impulse bandwidth can be determined by adjusting τ_o (the pulse width) to obtain a given E_r/E ratio.

3.4 Error Analysis: The principal sources of error in the measurement process are as follows:

(1)	Non-uniformity of the spectral lines (at 1 MHz bandwidth)	± 0.04 dB
(2)	Impedance mismatch	± 0.3 dB
(3)	Pulse width (at 100 n sec)	± 0.1 dB
(4)	CW signal level	± 0.1 dB
(5)	On-off ratio of pulse modulator (on-off ratio 70 dB)	± 0.03 dB
(6)	Insertion loss difference of SPDT of coaxial switch positions	± 0.025 dB
	Worst case error	± 0.61 dB
	By rss method	± 0.336 dB

3.4.1 If the pulse width is considered to be 100 nS, the first null will occur at 10 MHz on both sides of the CW frequency. The amplitude at 500 kHz on both sides of the spectrum center will be 0.4 percent below the spectrum center. Assuming the bandwidth of the receiver to be 1 MHz and its shape rectangular, the non-uniformity of the spectral lines could not contribute an error greater than 0.4 percent. In a practical case where the bandwidth is not rectangular, the error will be substantially less since the gain of the receiver will be less where the spectrum roll-off occurs.

3.4.2 Evaluation of the mismatch errors were considered under the worst case condition between the Spectrum Amplitude Calibration System and field intensity meter, power meter and the source. The analysis showed a total mismatch error (worst case) of ± 0.3 dB.

3.4.3 The pulse width is generated using a 49 nS charge line with a pulse generator. The pulse width can be determined within ± 1 percent or ± 0.1 dB measuring the electrical length of the charge line.

3.4.4 The CW signal level is measured using a thermistor mount and a power meter. The thermistor mount is calibrated to ± 1 percent from 100 MHz to 1 GHz. The power meter is accurate to ± 1 percent. The combined error is less than ± 2 percent or ± 0.09 dB.

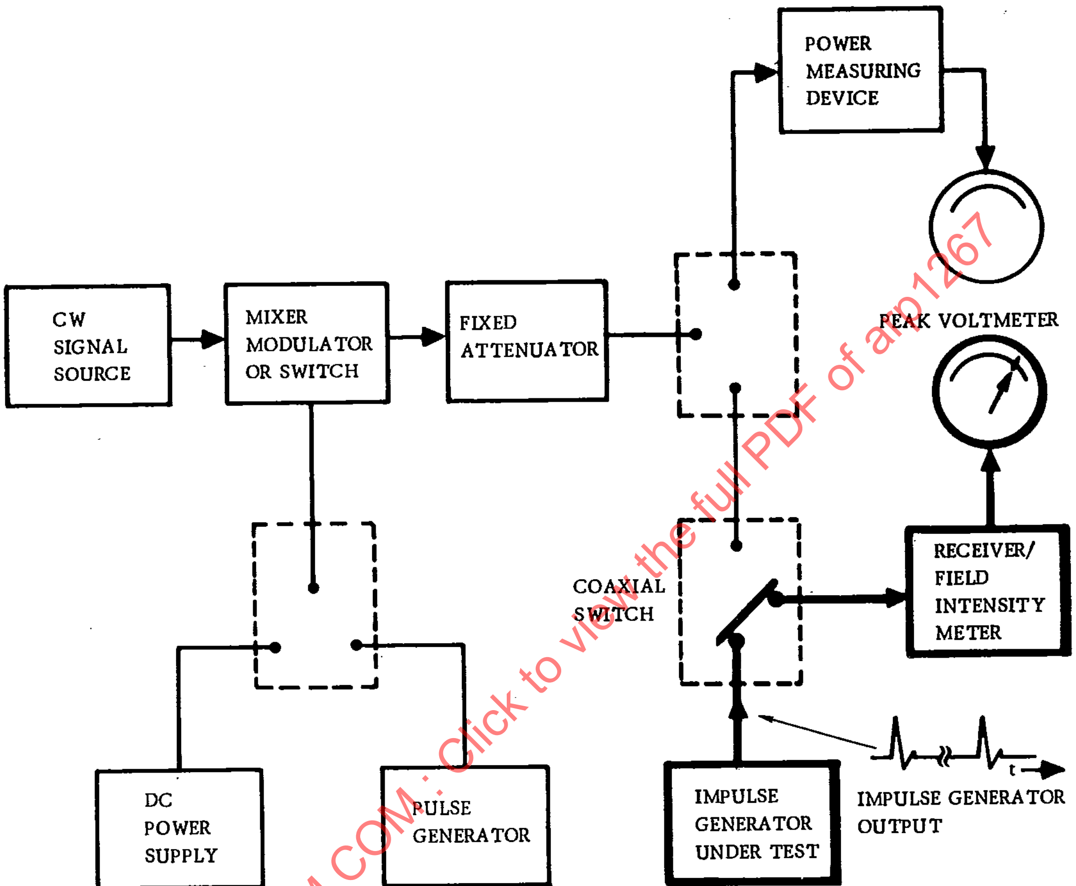
An additional error is incurred due to impedance mismatch. The input VSWR of the thermistor mount is less than 1.06 from 100 MHz to 1 GHz. The output VSWR mismatch error will be less ± 0.01 dB.

The total worst-case error in measuring the CW signal level will be less than ± 0.1 dB.

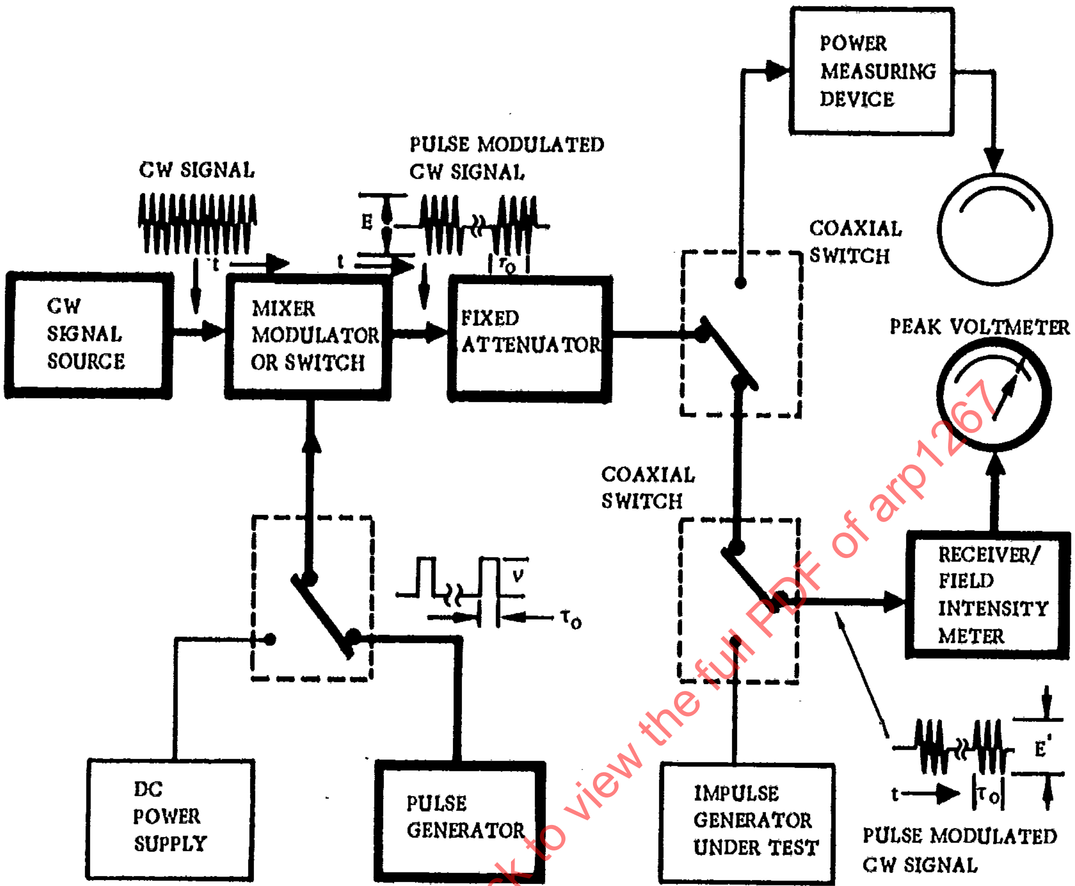
3.4.5 Lack of 100 percent pulse modulation will cause the center spectral line to be higher in amplitude than the surrounding spectral line. If the bandwidth of the receiver is 1 MHz and the on-off ratio of the pulse modulator is 70 dB, the error due to this effect will be +0.03 dB. This error will increase if smaller receiver bandwidths are used and the pulse width is held constant. This effect at narrower bandwidths can be compensated for by increasing the pulse width. In all cases the magnitude and sign of the error can be calculated and corrected for.

4. MEASUREMENT PROCEDURE - SPECTRUM AMPLITUDE

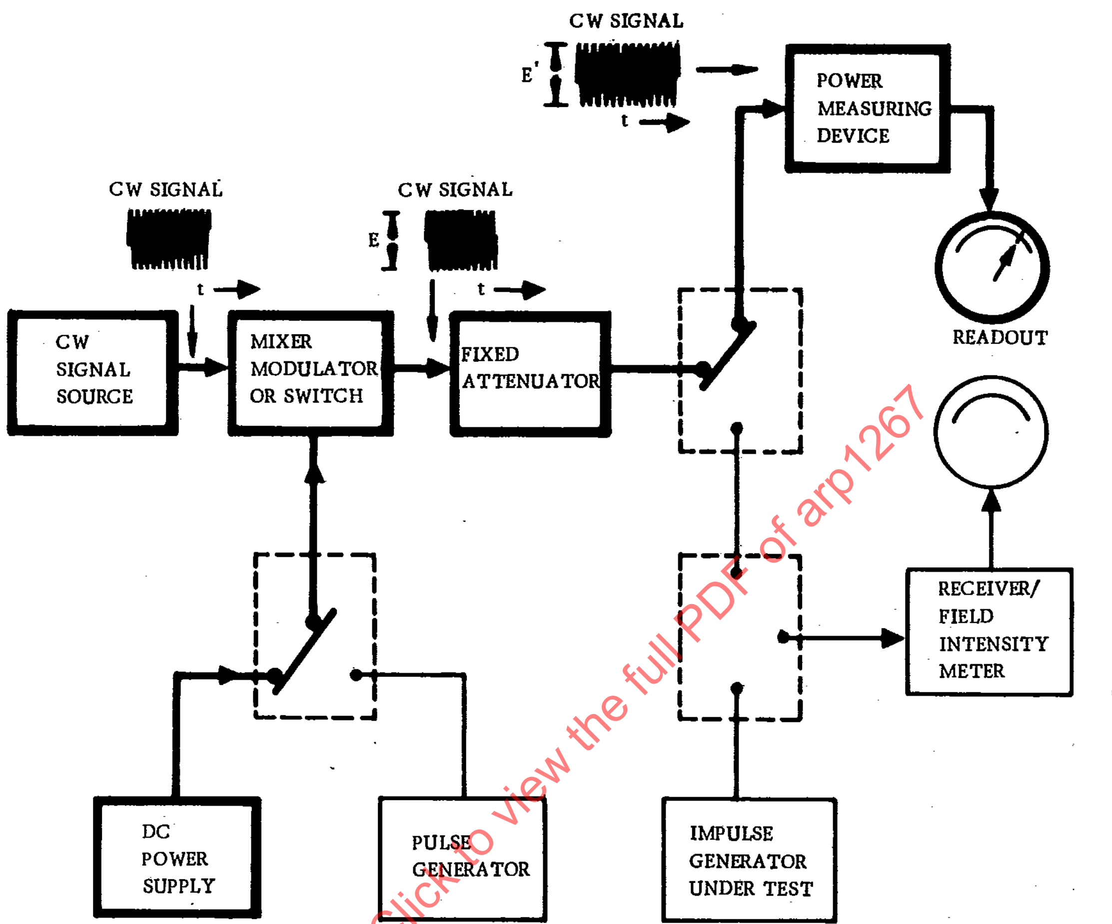
Signal paths and component connections are indicated by dark heavy lines.



4.1 The receiver is tuned to the calibration frequency f_1, and the receiver gain is adjusted for a convenient reference indication on peak voltmeter.



4.2 The frequency of CW signal source is set to the calibration frequency of the receiver f_1. The output level of the CW signal source is adjusted to duplicate reference indication established on receiver peak voltmeter in Step 4.1.



4.3 The CW power level is measured by the power measuring device.

4.4 The spectrum amplitude of the impulse generator is calculated using the following equation (in practice, the meter readout of the power measuring device is calibrated in terms of spectrum amplitude).

$$S_{rms} = \left[\sqrt{\frac{P\ (\text{watts})\ |Z\ (\text{ohms})|}{\cos\theta}} \cdot \tau_o\ (\text{seconds}) \right]$$

Where: P is the power level of the CW signal

$|Z|$ is the absolute impedance of the power measuring device

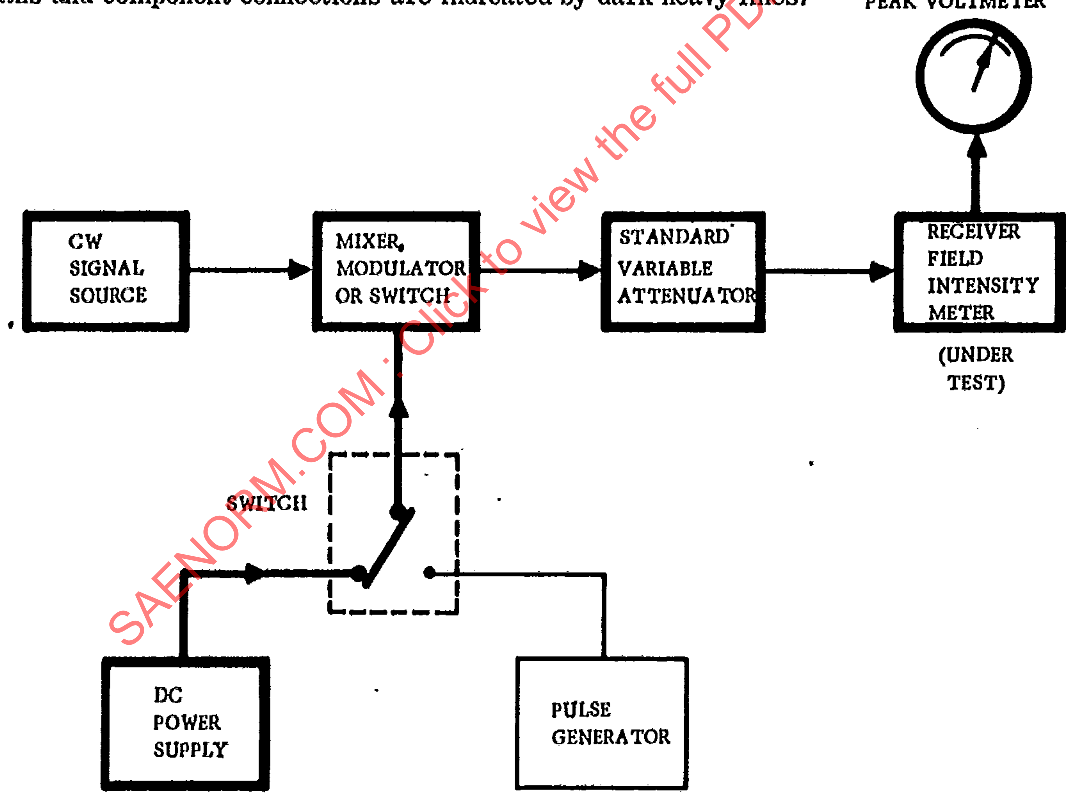
θ is the phase angle between the resistive component and the impedance $|Z|$, generally assumed to be $\approx 0^\circ$.

τ_o is the pulse width of the pulse signal used to modulate the CW signal

The spectrum amplitude calibration process is repeated for other calibration frequencies, e.g., f_2, f_3, f_4. . .f_n.

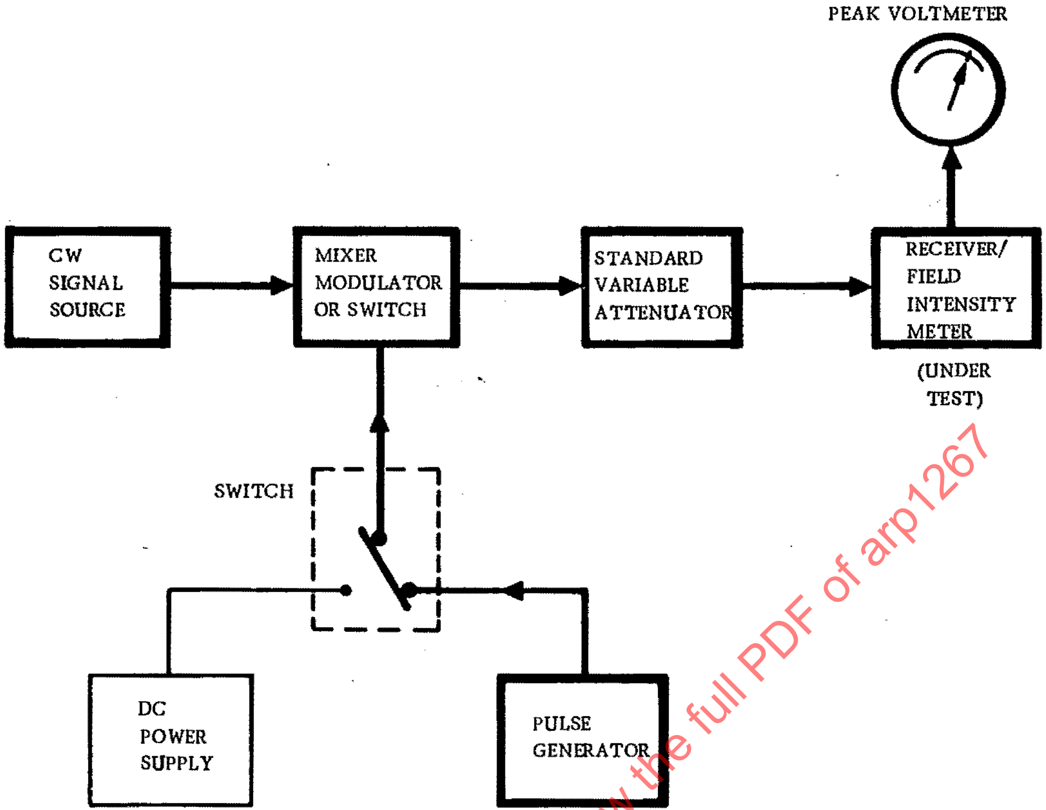
5. MEASUREMENT PROCEDURE - IMPULSE BANDWIDTH

Signal paths and component connections are indicated by dark heavy lines.



5.1 The receiver is tuned to the calibration frequency f_1. The gain of the receiver, the output level of CW signal source, and the variable attenuator are adjusted for a convenient reference indication on peak voltmeter. Note the variable attenuator setting.

The reference indication is mainly determined from prior knowledge of the nominal impulse bandwidth of receiver and the attenuator range of both receiver and the variable attenuator.



5.2 The variable attenuator is decreased (less attenuation) until the reference indication is established on peak voltmeter in Step. 5.1. Note variable attenuator setting.

5.3 The impulse bandwidth I_{BW} is calculated by the following formula:

$$I_{BW} = \frac{1}{\tau_o} \log_{10}^{-1} \frac{A}{20}$$

Where τ_o is the pulse width

A is the difference in attenuation in dB noted in Steps 5.1 and 5.2.

The measurement process is repeated for $f_2, f_3, f_4 \ldots f_n$.

PREPARED BY
SAE COMMITTEE AE-4, ELECTROMAGNETIC COMPATIBILITY

APPENDIX A - PULSE-MODULATED CARRIER ANALYSIS

To show the mathematical analysis, first consider a rectangular pulse train as shown in Figure A-1.

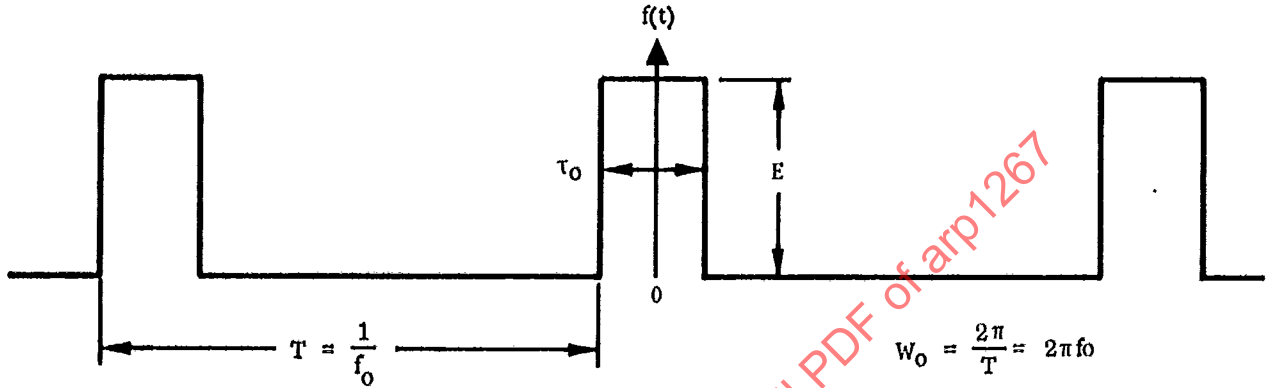


Figure A-1

From the exponential form of the Fourier series:

$$C_n = \frac{1}{T}\int_{-\tau_o/2}^{\tau_o/2} E\ e^{-jn\omega_o t}\,dt \qquad \text{(A-1)}$$

$$= \frac{1}{T}\left[-\frac{E}{jn\,\omega_o}e^{-jn\,\omega_o t}\right]_{-\tau_o/2}^{\tau_o/2}$$

$$= \frac{E}{T}\left[\frac{e^{jn\,\omega_o \tau_o/2} - e^{-jn\,\omega_o \tau_o/2}}{jn\,\omega_o}\right]$$

$$= \frac{2E}{n\omega_o T}\sin n\,\omega_o\frac{\tau_o}{2}$$

or this may be written in the form:

$$C_n = \frac{E\tau_o}{T}\left[\frac{\sin\left(n\,\omega_o \frac{\tau_o}{2}\right)}{n\,\omega_o \frac{\tau_o}{2}}\right] \qquad \text{(A-2)}$$

which is of the well-known form (sin X)/X, $X = n\omega_o \tau o/2$

The frequency spectrum is shown in **Figure** 2a and includes both negative and positive frequency domains.

The absolute amplitude at any frequency is the sum of the contributions of both -n and +n spectral lines, i.e., the absolute amplitude is equal to $2\left|C_n\right|$. The frequency spectrum is shown in **Figure 2b.**

The first null in the spectrum in **Figure 2b** will occur at a frequency of $1/\tau_o$ in respect to the center of the spectrum. Those spectral lines close to the center of the spectrum will have relatively the same amplitude when the bandwidth of the receiver or indicator is narrow relative to the pulse signal spectrum. For small angles (Eq A-2) the sine is very nearly equal to the angle in radians; hence, there is negligible drop-off until the angle exceeds about 0.04 radians and the sine term is nearly equal to unity.

Evaluation of Eq (A-2) for all spectral lines **within** $\pm$**5 percent (**$\pm$ **5 percent of** $1/\tau_o$) of the spectrum center shows the roll-off in amplitude will not exceed 0.4 percent or 0.04 dB.

The spectrum amplitude S in volts/Hz at the spectrum center may be determined by dividing the above equation by 1/T, the repetition frequency, thus:

$S = 2\, E_R\, \tau_{oR}$

however, since $E_R\, \tau_{oR}$ is equal to the area (A_R) of the rectangular pulse in the time domain,

$S = 2\, A_R$

Next consider a CW signal, modulated by a rectangular pulse train as shown in Figure 3.

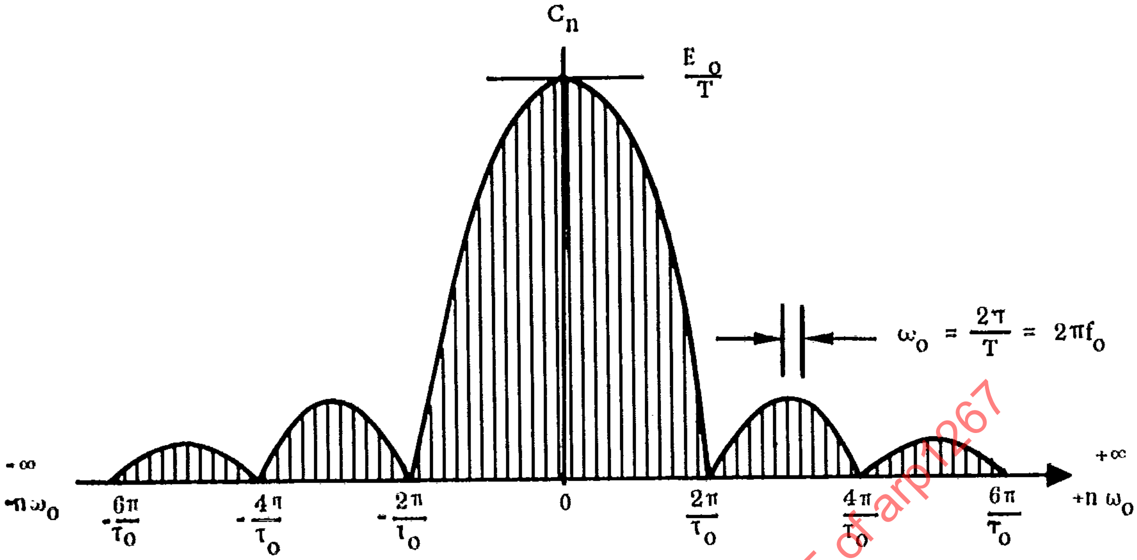


Figure A-2a

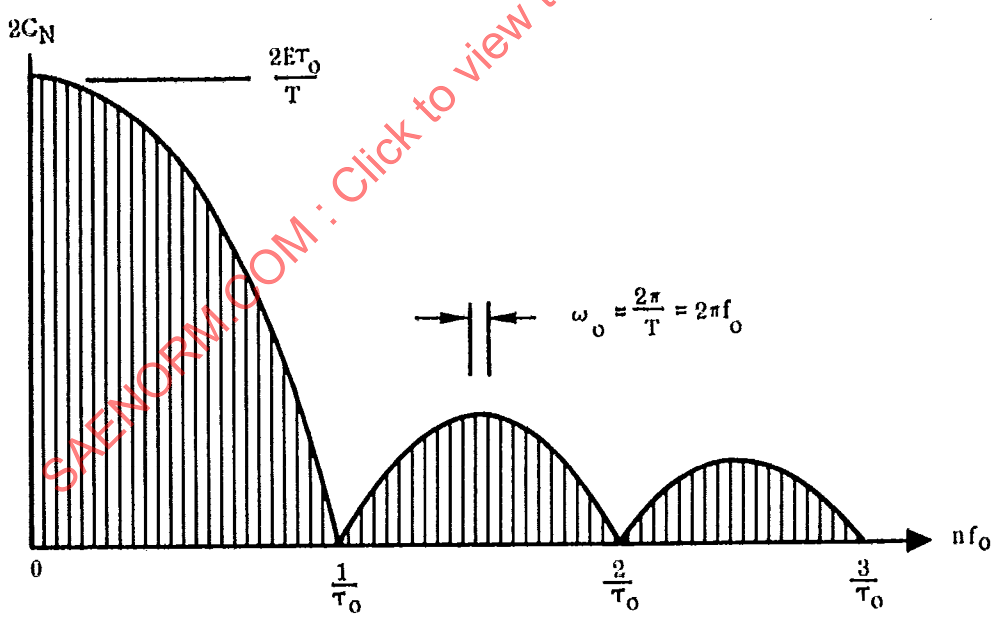


Figure A-2b

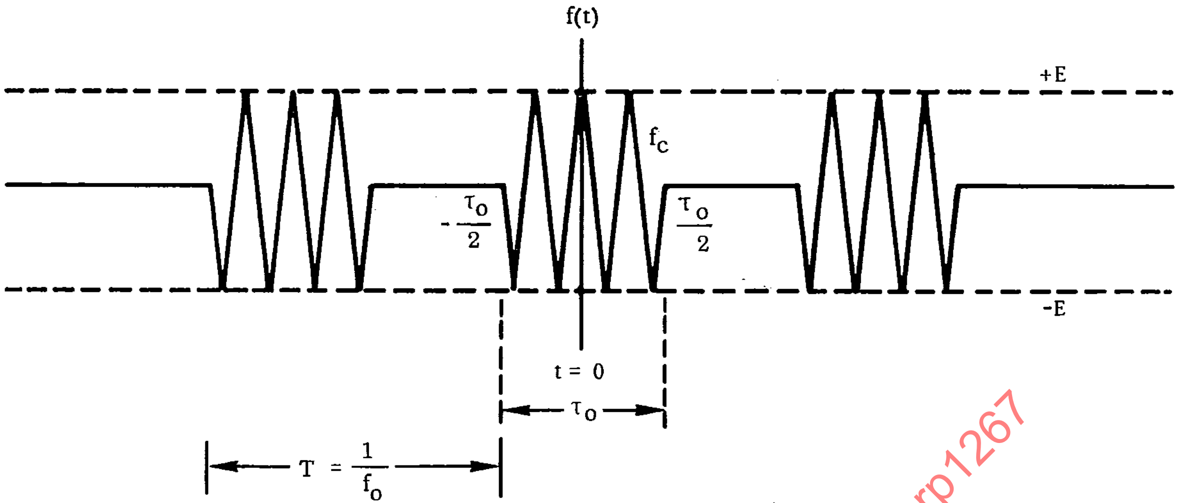


Figure A-3

$$f(t) = E \cos \omega_c t, \quad -\frac{\tau_o}{2} \leq t \leq \frac{\tau_o}{2}$$

$$f(t) = 0, \quad \text{elsewhere}$$

and $\omega_o = \frac{2\pi}{T}$

The Fourier coefficient may be represented as:

$$Cn = \frac{1}{T} \int_{-\tau_o/2}^{\tau_o/2} f(t)\, e^{-jn\,\omega_o t}\, dt \qquad \text{(A-3)}$$

Since: $$\cos \omega_o t = \frac{e^{j\omega_c t} + e^{-j\omega_c t}}{2} \qquad \text{(A-4)}$$

$$C_n = \frac{E}{2T} \int_{-\frac{\tau_o}{2}}^{\frac{\tau_o}{2}} \left(e^{j\omega_c t} + e^{-j\omega_c t}\right)\left(e^{-jn\omega_o t}\right) dt$$

$$= \frac{E}{2T} \int_{-\frac{T}{2}}^{\frac{\tau_o}{2}} \left[\left(e^{j\omega_c t}\right)\left(e^{-jn\omega_o t}\right) + \left(e^{-j\omega_c t}\right)\left(e^{-jn\omega_o t}\right)\right] dt$$

$$= \frac{E}{2T} \int_{-\frac{\tau_o}{2}}^{\frac{\tau_o}{2}} e^{-jt(n\omega_o - \omega_c)} + e^{-jt(n\omega_o + \omega_c)} dt$$

$$= \frac{E}{2T} \left\{ \left[-\frac{1}{j(n\omega_o - \omega_c)} e^{-jt(n\omega_o - \omega_c)}\right]_{-\frac{\tau_o}{2}}^{\frac{\tau_o}{2}} + \left[-\frac{1}{j(n\omega_o + \omega_c)} e^{-jt(n\omega_o + \omega_c)}\right]_{-\frac{\tau_o}{2}}^{\frac{\tau_o}{2}} \right\}$$

$$= \frac{E}{2T} \left\{ -\frac{1}{j(n\omega_o - \omega_c)} \left[e^{-j\frac{\tau_o}{2}(n\omega_o - \omega_c)} - e^{j\frac{\tau_o}{2}(n\omega_o - \omega_c)}\right] - \frac{1}{j(n\omega_o + \omega_c)} \left[e^{-j\frac{\tau_o}{2}(n\omega_o + \omega_c)} - e^{j\frac{\tau_o}{2}(n\omega_o + \omega_c)}\right] \right\}$$

$$= \frac{E}{T} \left[\left(\frac{e^{j\frac{\tau_o}{2}(n\omega_o - \omega_c)} - e^{-j\frac{\tau_o}{2}(n\omega_o - \omega_c)}}{2j(n\omega_o - \omega_c)}\right) + \left(\frac{e^{j\frac{\tau_o}{2}(n\omega_o + \omega_c)} - e^{-j\frac{\tau_o}{2}(n\omega_o + \omega_c)}}{2j(n\omega_o + \omega_c)}\right)\right]$$