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THE EFFECT OF MOTOR CAR IGNITION NOISE ON TELEVISION SERVICES.

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ABSTRACT

THE EFFECT OF MOTOR CAR IGNITION INTERFERENCE ON TELEVISION SERVICES.

The peak field strength of car ignition interference in the V.H.F. band is a maximum in the 30-50 M.C. region and a minimum in the 60-125 M.C. region, and rises slowly at higher frequencies to a saturation level. In the short wave band below 25 M.C. the peak field is considerably less than in the V.H.F. band and falls rapidly as the frequency is lowered, being negligibly small in the medium wave band.

It is anticipated that the peak field strength at a 30 ft. receiving antennae spaced 100 ft. from a car will be of the order of 10 M.V./metre with the picture bandwidth, which it is proposed to use for the Australian Service. Under the same conditions the peak field strength associated with the F.M. sound channel is likely to be 0.1 M.V./m. per 10 K.C. of bandwidth.

It is anticipated that a well designed receiver will fail first on the sound channel as the result of car ignition interference, and that a satisfactory level to combat the above interference would be 8.5 M.V./metre.

1. INTRODUCTION

In connection with the proposed introduction of Television Services into the Commonwealth it became necessary to know the extent to which motor car ignition noise restricted the service area. A six-cylinder motor car engine rotating at 2000 R.P.M. will radiate 100 main pulses of ignition interference per second, the duration of the pulses being less than ½ micro-seconds. For each main ignition pulse there are usually a train of secondary pulses smaller in amplitude than the main pulse and delayed by periods ranging from a few micro-seconds up to 1.5 milli-seconds. The number of such secondary pulses vary with the make of vehicle but on the average there are 16 secondary pulses for each main pulse, or a pulse rate of 1600 per second, which means that there will be 64 pulses per picture on the average. Allowing 2 picture "persistence of vision" 128 black spots will be visible at any instant, representing a total area 1/1250 of the area of the picture. This state of affairs will only exist if the secondary interference pulses are strong enough to operate the receiver. It has been found that suppression resistors installed in a car attenuate the secondary pulses to a relatively greater extent than the main pulse, and reduce the number and duration of the secondary pulses.

In addition to interfering with the picture content as above, ignition interference can cause loss of synchronisation, which has a more disastrous effect on the picture. This is being largely overcome in U.S.A. by the use of "fly-wheel" synchronisation in the receiver. A simple limiting device will usually be necessary to limit the noise peaks at the level of the synchronising pulses.

In regard to the effect of ignition noise on the F.M. sound channel, it will be shown that under typical noise conditions and with U.S.A. standards, a field intensity of approximately 8.5 M.V./m. is required, to ensure a peak output signal-noise ratio of 50 db. This appears to be a better criterion for fixing the required field intensity to combat ignition noise, since the results are substantially independent of receiver design, whereas the picture interference (particularly with a strong interfering field) is dependent on the quality of receiver design.

2. VARIATION OF IGNITION NOISE FIELD WITH FREQUENCY

It has been found experimentally by George (Ref.1.) that the ignition field strength under typical conditions is substantially independent of frequency in the range 60-450 M.C. His measurements were made at a distance of 100 ft. from a variety of vehicles and with a receiving aerial 35 ft. in height. He measured the peak field intensity over a bandwidth of 10 K.C. in a series of "spot" measurements at frequencies of 40, 60, 100 M.C. and so on up to 450 M.C. Later Pressey and Ashwell (Ref.2) made "spot" measurements over a 2.5 M.C. bandwidth with readings taken at much closer frequency spacings, using only Vauxhall cars. Their results, particularly with horizontal polarisation, showed a very pronounced minimum of interference at a frequency of 70 M.C. This minimum was probably present but not apparent in George's measurements because of the wide frequency spacing between measurements; its significance will be developed in the course of this report. It has further been established experimentally in England (Ref.6), that the fundamental frequency of the interference, which is in effect a modulated carrier, varies between 30 and 50 M.C. according to the type of vehicle. For analytical purposes this carrier frequency can be regarded as being modulated by an exponentially decaying pulse. It then becomes apparent that the frequency spectrum is made up of a carrier plus an infinite number of upper and lower sidebands centred around the carrier frequency. The side bands have a maximum amplitude near the carrier frequency with progressively falling amplitude at frequencies above and below the carrier frequency, but the frequency spectrum of the side-bands is modified somewhat by the laws of radiation and propogation of electromagnetic waves. The frequency spacing between side-bands is the recurrence rate of the ignition pulses, which for ordinary car speeds is of the order of 100 c/s. The results are not significantly changed if the ignition pulses are regarded as discreet pulses, occurring at irregular intervals of time, at least as far as the peak voltage taken over as appreciable bandwidth is concerned. It is the pulse of greatest amplitude which determines the peak voltage of interference and consequently only the main ignition pulse need be considered from a peak voltage point of view; the secondary pulses do not add to the peak voltage but as explained above they can add very considerably to the interference on a television screen.

In the Appendix the pulses of high frequency current in the car ignition circuits are broken up by Fourier analysis into the component side-bands. The side-bands can be classified in two groups A and B, corresponding side-bands of each group having the same frequency, but being 90° out of phase. The A group are characterised by being all "in-phase" at the instant of pulse build up and they all pass through their maximum amplitude at this instant, whereas the B group are all passing through zero amplitude at this instant. For frequencies more than a few megacycles per second above the fundamental or carrier frequency fc, the A side-bands are proportionate to $\left(\frac{1}{(f-fc)}^2 + \frac{1}{(f+fc)}^2\right)$ and the B side bands are approximately proportionate to $\frac{1}{f-fc}$ where f is the actual side-band frequency. For very narrow bandwidths embracing only one side-band, the B side-band is predominant because of its superior amplitude. In practical applications which usually involve at least 100 side-bands, the A side-bands are predominant in determining the peak voltage since they all add in phase at one instant.

If the ignition circuits within the car are assumed to be equivalent to a loop aerial, then for a given current the free space radiated field strength will be proportional to f^2, but the A side-band peak current is proportional to $\frac{1}{(f-fc)}^2 + \frac{1}{(f+fc)}^2$ and consequently the free space radiated field strength is proportional to $f^2\left(\frac{1}{(f-fc)}^2 + \frac{1}{(f+fc)}^2\right)$

Due to the effect of the ground reflected ray the free space field must be multiplied by a factor directly proportional to frequency to get the actual field strength. This gives the final result that the actual field strength is proportional to $f^3\left(\frac{1}{(f-fc)}^2 + \frac{1}{(f+fc)}^2\right)$. It is apparent from the nature of this factor that the peak field strength for upper side-bands will have a minimum value at some frequency. Analysis shows that the minimum occurs for a value of f = 2.5 fc. If fc = 30 M.C. the minimum would occur at 73 M.C. and as stated above Pressey and Ashwell found a very distinct minimum occurring at 70 M.C. If fc is assumed as 25 or 30 M.C. and the above expression is plotted against frequency, a curve very similar to Pressey and Ashwell's experimental curve for horizontal polarization is obtained. The curve has the following general characteristics;

(a) A broad minimum in the 60-75 M.C. region;
(b) A sharp maximum in the 30 M.C. region;
(c) At frequencies higher than the 60-75 M.C. region the ignition noise field rises continuously to a saturation level;

Pressey and Ashwell's curve does not show characteristic (b) very plainly as their measurements did not extend below about 42 M.C., but most other experimenters have reported this sharp maximum at the fundamental or carrier frequency. In references 3 and 4 it is reported that the 90 M.C. field intensity is from 9-19 db less than the 40-45 M.C. field intensity depending upon the type of car. These results could be in accordance with the above formula if suitable values of fc are assumed for each make of vehicle. The saturation level mentioned in (c) above is brought about when the frequency is such that the direct and indirect rays are in phase. From this point the interference will simply oscillate about the free space level, which is independent of frequency at high frequencies. If other curves are plotted from the above formula assuming values for fc varying from 30-50 M.C. the broad minimum will vary from 75-125 M.C. These variations represent the variations with different types of cars, and in general it can be said to be a minimum in the frequency band 60-125 M.C. In the short wave band below 25 M.C., the peak ignition noise field strength is in general considerably less than that in the V.H.F. band considered above. This is obvious from the above formula.

3. IGNITION INTERFERENCE TAKEN OVER A 6 M.C. PICTURE CHANNEL.

The measurements of Pressey and Ashwell (Ref. 2) have indicated that with a 2.5 M.C. bandwidth and a receiving aerial height of 10 ft. the receiver field strength at a distance of 30 ft. from a car at 200 M.C. is of the order of 15 mV/m. peak. On this basis the field strength at a distance of 100 ft. and with a 30 ft. aerial could be expected to be 4 M.V/m. peak for 2.5 M.C. bandwidth and 10 M.V./m. peak with 6 M.C. bandwidth.

It is difficult to assess the degradation of the picture by ignition noise without some experimental evidence with receivers. It seems likely, however, that with a sound carrier field strength of 8.5 M.V./m. as recommended below, a single vehicle under the above typical conditions will not cause significant interference to the picture of a well designed receiver and only occasional loss of synchronisation to a receiver not incorporating "flywheel" synchronisation. If, however, there are a number of cars giving the above quoted peak field (10 M.V./m.), then the area of black interference dots increases in direct proportion to the number of cars, and in addition the probability of loss of synchronisation increases in direct proportion to the number of cars. With the sound, however, the peak noise is not likely to be significantly increased by increasing the number of cars and consequently the sound is not noticeably degraded. The reason for the different effects of an increasing number of cars on sound and vision is, of course, explained by the fact that the picture builds up on a sequential or time division basis where as the sound is the result of a frequency variation process with the degree of interference being largely determined by its peak voltage.

It is considered that it would be instructive to measure the peak field strength of typical car ignition noise taken over the proposed Australian picture band width of 5½ M.C, at carrier frequencies of 60 and 200 M.C. This is recommended because of the lack of agreement between measurements made by different experimenters on small bandwidths. The procurement of an American television receiver would provide the easiest means of taking such measurements.

4. IGNITION INTERFERENCE ON THE SOUND CHANNEL.

The peak noise voltage is directly proportional to bandwidth and consequently for a 30 K.C. bandwidth (audio response 15 K.C.) the peak ignition noise field strength is $3 \times 0.1 = 0.3$ M.V./meter, since George's measurements gave a field of 0.1 M.V./meter for 10 K.C. bandwidth. If the sound carrier field strength is 8.5 M.V./m. then the ratio of R.M.S. carrier to peak noise voltages is $\frac{8.5}{0.3} = 28.3 = 29$ db.

If the carrier is 100% modulated with an A.M. signal the ratio of peak signal to peak noise A.M. output is $29 + 3 = 32$ db. If the audio response is 15 K.C. and the peak swing ± 25 K.C. (deviation ratio $\frac{25}{15}$) Crosby's experimental curves (ref. 5) give the F.M. improvement factor as 8 db, and consequently the F.M. peak output signal-noise ratio is 40 db. With 75 microsecond de-emphasis, Crosby's curves (Ref. 6) indicate that after allowing for a 2½ db reduction of deviation at the transmitter, a nett advantage of 10 db. is gained by de-emphasing the F.M. impulse noise, giving a final peak output signal-noise ratio of 50 db.

Referring further to Crosby's curves (Ref. 5) the peak output "threshold" signal-noise ratio is 25.5 db when using an R.F. channel 50 K.C. wide to accommodate the F.M. swing. But with the standard practice of using a 200 K.C. channel, the threshold level will be increased by 12 db. to 37.5 db. Hence the assumed sound carrier field strength of 8.5 M.V./m. leaves a margin of 12.5 db above the "noise threshold", the point at which intolerable noise and distortion become evident. This 12½ db. margin should be about adequate and the 50 db. peak output signal-noise ratio should be adequate but not excellent. Increasing the peak swing to ± 75 K.C. as in the American sound broadcasting service increases the signal-noise ratio about 10 db. without altering the "threshold" level. The F.C.C. consider that a signal of 5 M.V./m. is adequate for this service so that under the interference conditions assumed above the peak output signal-noise ratio would be 55 db, and the noise "threshold" level remains unchanged at a peak output signal-noise ratio of 37.5 db.

5. COMPARISON OF 60 M.C. AND 200 M.C. CHANNELS FROM AN IGNITION NOISE POINT OF VIEW

According to the 10 K.C. measurements of George (ref.1) the peak ignition noise field strength is the same at 60 and 200 M.C., and consequently for a given field strength the ignition interference to the sound is the same at the two frequencies. But since a given transmitted power usually gives a higher field strength at the higher frequency, it follows that the sound signal-noise ratio will be higher at the higher carrier frequency. In regard to vision one experimenter (ref.2) measuring over a 2.5 M.C. bandwidth found the 200 M.C. peak ignition noise about 6 dB higher than the 60 M.C. peak ignition noise. Since the difference of field strength for a given power is also of the order of 6 dB., it follows that the signal-interference ratio will be substantially the same in the two cases.

6. CONCLUSIONS.

The field strength of ignition interference is to a first approximation independent of frequency in the V.H.F. range 60-300 M.C. There is however a broad minimum of interfering field in the 60-125 M.C. region, and a sharp maximum in the 30-50 M.C. region.

The actual field strength taken under typical conditions over a 6 M.C. bandwidth is of the order of 10 M.V./m. peak at 200 M.C. The interfering effect on the picture is directly proportional to the number of cars causing interference, even though the peak voltage is substantially independent of the number of cars.

It is believed that a well designed receiver, in the presence of severe ignition noise will fail on the sound channel first, and that 8,5 mV/m. would be a satisfactory sound carrier level. The presence of an appreciable number of interfering vehicles may upset this principle making vision more vulnerable than sound.

From the view point of ignition noise interference there is only a very slight advantage in the use of a 200 M.C. carrier frequency as opposed to 60 M.C.

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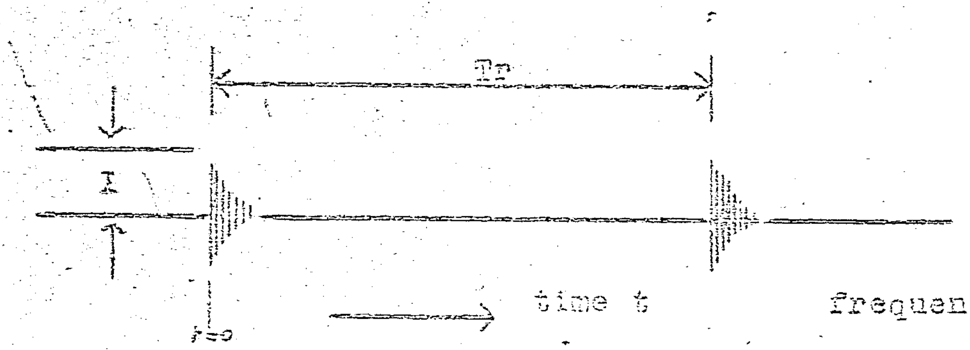
APPENDIX.

The Frequency Spectrum of an Exponentially Decaying R.F. Pulse.



Analysis of the Envelope.

First of all make a Fourier Analysis of the envelope above the zero line i.e. a pulse of maximum amplitude I and decaying exponentially according to the law $i = Ie^{at}$ where a is a constant. Then the various components of the envelope are given by the expression -

$$f(t) = \tfrac{1}{2} Ao + \sum_{n=1}^{\infty} (An \cos nW_ot + Bn \sin nW_ot)$$

where $W_o = 2\pi f_o$ = the angular recurrence frequency of the pulses
$\tfrac{1}{2}A_o$ = is the average amplitude or D.C. component of the envelope.

n is an integer having all values from 1 to ∞. In the present case the Fourier coefficients A_n and B_n are most simply obtained from the complex coefficient $\underline{Dn}$ where $\underline{Dn} \doteq An - JBn$. $\underline{Dn}$ in itsturn is obtained from

$$2\underline{Dn} = \frac{2}{Tr} \int_0^{Tr} Ie^{-at} e^{-jnW_ot} dt.$$

Integrating $2\underline{Dn} = - \frac{2I}{Tr} \frac{e^{-(a + j\,nW_o)Tr} - 1}{a + j\,nW_o}$

The value of a and Tr are such that $e^{-(a + j\,nW_o)Tr}$ is extremely small compared with 1 and can therefore be neglected leaving

$$2\underline{Dn} = \frac{2I}{Tr} \frac{}{(a + j\,nW_o)} = \frac{2I}{Tr} \frac{(a - j\,nW_o)}{a^2 + (nW_o)^2}$$

Hence $An = \frac{2I}{Tr} \frac{a}{a^2 + (nW_o)^2}$ and $Bn = \frac{2I}{Tr} \frac{nW_o}{a^2 + (nW_o)^2}$

Hence the frequency spectrum of the envelope is

$$f(t) = \frac{I}{Tra} + \sum_{n=1}^{\infty} \frac{2I}{Tr(a^2 + n^2 W_o^2)} \left\{ a \cos nW_o t + nW_o \sin nW_o t \right\} \ldots (2)$$

2. <u>Frequency Spectrum of the R.F. Pulse.</u>

If $W_c = 2\pi f_c$ is the angular frequency corresponding to the fundamental or carrier frequency fc of the pulse, then by the well known amplitude modulation laws for upper and lower side bands the frequency spectrum of the R.F. pulse is

$$F(t) = \frac{I}{Tra} \cos W_c t + \sum_{n=1}^{\infty} \frac{I}{Tr(a^2 + n^2 W_o^2)}$$

$$\left\{ a \cos (W_c \pm nW_o)\, t + nW_o \left\{ \sin (W_c + nW_o)\, t - \sin (W_c - nW_o)\, t \right\} \right\} \ldots ($$

If the terms of equation (3) are added pair by pair Cos $\omega_c t$ the result will be the envelope (equation 2) multiplied by ~~cos~~, which is sufficient verification that equation (3) contains all the frequency components of the R.F. pulse. An inspection of equation (3) shows that although the sine terms are of larger amplitude than the cosine terms for large values of n, the fact that successive harmonics have constant phase increments ensure that the sum of the sine terms taken over an appreciable bandwidth will be substantially zero at all instants. On the other hand the cosine terms at the instant (t = 0) of pulse build up are all in phase and passing through maximum amplitude and taken over an appreciable bandwidth these components determine the peak voltage of the resultant pulse. At other instants slightly or considerably removed from t = 0, Tr, 2Tr, etc. the cosine components are also substantially zero when summed over an appreciable bandwidth. Consequently for the purpose of this report the sine terms can be neglected and equation (3) reduced to -

$$f(t) = \frac{I}{Tra} \cos W_c t + \sum_{n=1}^{n=\infty} \frac{Ia}{Tr\,(a^2 + n^2 W_o^2)}$$

$$\left\{ \cos (W_c + nW_o)\, t + \cos (W_c - nW_o)\, t \right\} \ldots (4)$$

Since $\cos(W_c - NW_o)\, t = \cos(nW_o - W_c)\, t$, equation (4) indicates that it is possible to get two side bands of the same angular frequency W and unequal amplitudes but adding in phase. For the case where $W > W_c$. $W = W_c + NW_o = N'W_o - W_c$ where N and N' are positive integers chosen to satisfy this equation, i.e. $N'Wo = W-Wc$ and $N''Wo = W + Wc$. Substituting in equation (4) the sum S, of these two specific side bands is given by

$$s = \frac{Ia}{Tr}\left(\frac{1}{a^2 + (W-Wc)^2} + \frac{1}{a^2 + (W + Wc)^2}\right) \cos wt.$$

Since we are only concerned with peak values and all components have their peak values adding in phase at $t = 0$, it is not essential for the frequencies of the two components to be exactly equal and when a number of these pairs of average angular frequency W are added over an appreciable bandwidth B, the total peak voltage $S_B = \frac{I\ a\ N_B}{Tr}\left(\frac{1}{a^2 + (W-Wc)^2} + \frac{1}{a^2 + (W + Wc)^2}\right)$ where $2N_B$ is the total number of side bands in a bandwidth B, of which half have amplitudes proportional to $\frac{1}{a^2 + (W-Wc)^2}$ and the other half have amplitudes proportional to $\frac{1}{a^2 + (W+Wc)^2}$ Since the frequency spacing of side bands of either kind is $\frac{1}{Tr}$ then $\frac{N_B}{Tr} = B$ and consequently

$$S_B = I\ a\ B\left(\frac{1}{a^2 + (W-Wc)^2} + \frac{1}{a^2 + (W + Wc)^2}\right) \dots\dots (5)$$

Note that S_B is independent of the recurrence frequency of the pulses so that equation (5) applies equally well for a discreet pulse, the peak occurring at the instant of build up ($t = 0$) of the pulse.

When W is less than Wc, equation (5) gives the peak current but the derivation is slightly different, both terms being derived from the second term of equation (4).

To get an idea of the value of "a" for a typical car-ignition pulse, assume that the current pulse decays to 36% ($\frac{1}{e}$) of its initial amplitude in 0.25 microseconds.

Then $e^{-a\tau} = 0.36 = \frac{1}{e}$ and $a\tau = 1$

i.e. $a = \frac{1}{0.25 \times 10^{-6}} = 4 \times 10^6$

If f and fc are the frequencies corresponding to angular frequencies W and Wc, when f-fc = 3 M.C. ($W-Wc = 3\times10^6 \times 2\pi = 18.85\times10^6$) and $\frac{W-Wc}{a} = \frac{18.45}{4} = 4.7$ and $\frac{(W-Wc)^2}{a^2} = 22.3$

Hence for f-fc = 3 M.C. a^2 is practicably negligible compared to

$(W-Wo)^2$ and for higher values of $f-fc$, a^2 decreases very rapidly in comparison with $(W-Wo)^2$ and $(W + Wc)^2$ and under these conditions equation (5) reduces to -

$$Sp = I\ a\ B\left(\frac{1}{(W-Wc)^2} + \frac{1}{(W + Wc)^2}\right) \qquad (5A)$$

$$= \frac{I\ a\ B}{4\pi^2}\left(\frac{1}{(f-fc)^2} + \frac{1}{(f + fc)^2}\right) \qquad (5B)$$