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Performance Simulation of HF-VHF Mobile Radio Systems in a Tactical Vehicle

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ABSTRACT

A simulation process evolved for evaluating the performance of HF-VHF multi-radio set configuration in a tactical command vehicle is discussed. Algorithms and performance models used in the simulation process are briefly described. Simulation process is for a specific application in a defined area of deployment under known operating situations. Performance simulation also includes an interference simulation model corresponding to the system model so that a real world situation is analysed to the practicable extent. Wherever statistical data or manufacturer's design data is not available, suitable default values are assumed for applicable, battlefield scenario quoted in the literature. This simulation tool can be extended to many applications (with modification to RF power of transmitters, receiver sensitivity, frequency separation, distance separation, channel spacing, frequency range, communication range, etc. of tactical vehicles operating in combinations of HF-VHF-UHF regions).

Keywords: Performance model, EMI model, IMI, inter modulation power, CNR/SNR, frequency separation, propagation loss, received signal power, distance separation, system noise, fundamental interference margin

1. INTRODUCTION

In tactical situations, in particular, tracked vehicles are always under constraints for an efficient communication system unlike their civilian or commercial mobile radio system, where these do not have favourable environment or choice. Basically, military tactical radio-communication systems suffer due to the following reasons:

a) Base station is always temporary and is required to move at a short notice and replay, which may not have favourable high exposed ground clearly necessitating non line-of-sight [NLOS] conditions working.

b) Quality of transmission/reception and equipment reliability are of paramount importance to the soldiers.

c) Modulation scheme should be user-friendly so that minimum noise, maximum usability with utmost protections for jamming sources and speech privacy are achieved. This is always a trade-off wrt to performance. Also, the tactical situation is highly dynamic and real scenario plays an important role wrt to screening effect, fading and atmospheric attenuation of radio signals, especially in HF radio sets.

For this study, an attempt has been made for studying eight operating situations. (as discussed in Section 5 under interference simulation model)

2. METHODOLOGY FOR SIMULATION MODEL

Figure 1 shows the simplified schematic of a simulation model for performance evaluation, leading to frequency assignment for various scenarios experienced in tactical situations while using HF-VHF mobile radio system in tactical vehicles. This involves four sequential steps where the prime engineering and operational parameters are defined as basic inputs for the first step. In the second step, propagation loss is predicted, noise models generated, and performance algorithms are formulated.In the third step, performance measure is defined so that the objectives of simulation are achieved /realised models in step 4. This simulation model is suitable for frequency assignment specific to area of operation for the given simulation which can be modified for other applications.

Similarly, depending upon the types of radio systems used, viz., HF/VHF/UHF, their technical and operational parameters too can be altered to examine the ideal situations. Thus, alternate solutions to different problems can also be found using this simulation model. In this particular simulation, the most appropriate practical situations will only be considered.

The focus here is on a tactical command vehicle, which has one HF radio link and two identical VHF links. Frequency spectrum is from 1.6 MHz to 88 MHz and both transmission and reception qualities are to analysed along with operational requirements. Frequency separation between the three links will be the main issue for EMI free operations, in a real world.

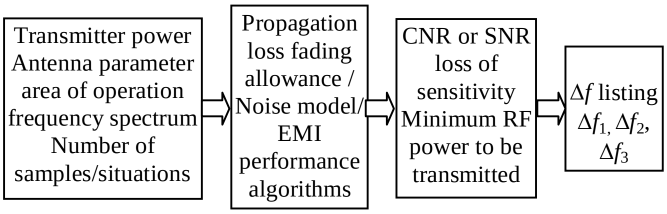

Figure 1. Simplified schematic of a simulation model.

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3. GENERAL ALGORITHM OF COMPUTER SIMULATION MODEL

The generalised term of algorithm used to implement the computer simulation model[1] is shown in Fig. 2. The implementation comprises three stages namely, input data file generation, software formulation, and program execution. Equipment parameters, either from manufacturer's data or measured data, such as transmitter power levels, antenna type, height, gain, etc. were fed to the input file. Various operating situations were considered in respect of multi-radio set operations. Under all operating situations, quality of signal SNR, EMI effect was considered.

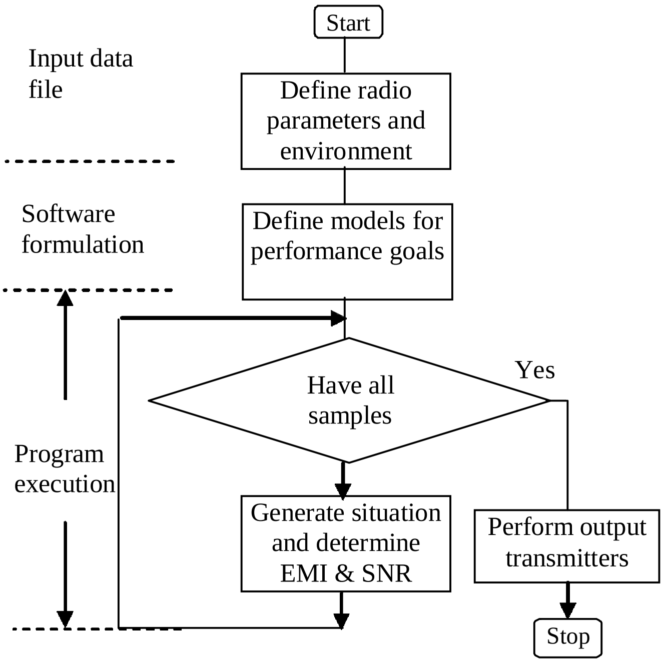

Figure 2. Flow chart for a simulation model.

Under all operating situations, when three transmitters are operating simultaneously, the following two major disturbances occur in the vehicle.

(a) The vehicle EM ambient level rises considerably because of strong radiations of three carriers and their harmonics.

(b) Any two carriers and/or their harmonic emissions/ spurious signals can get mixed to produce sum and difference frequencies and result as intermodulation EMI. This mixing again can occur either at any transmitter or in any receiver. Also external AM-DSB signal at any frequency can produce a cross modulation EMI at HF receiver when tuned to the desired signal. [AM signals in 1-30 MHz,108-130 MHz and 225-400 MHz frequencies].

Similarly, when two strong transmitters are transmitting simultaneously, the third receiver is the most affected and its intended signal may get degraded or jammed. RF power level of adjacent transmitter in the same vehicle contributes considerably. In this case, receiver intermodulation and undesirable response of receiver have been encountered. EMI effect could be mitigated with filter selectivity characteristics in the front-end of the receiver. Once these aspects are simulated for a given situation, optimum performance excepted can be computed.

4. PERFORMANCE MODELS

Performance models[2] based on judicious choice of analytical equations, consideration of realistic situation well supported by simulation techniques enable to arrive at proper analysis of performance goals of communication system. Longly-Rice model for propagation loss predictions has been widely accepted in military radio equipment.To dertermine the potential EMI effect due to undesired emitter it is necessary to know the filter selectivity of the desired receiver. An interfering carrier with a very strong level will be attenuated to have a reduced interferencing effect, if its frequency is sufficiently offset from the desired frequency. If the interfering carrier is close or identical to desired frquency of receiver, the results could be maximum degradation to total jamming/catastrophic.

The difference [*pd-pu*] between desired power output response (*pd*) at frequency (*fd*) to undesired output response at frquency (*fu*) is the amount of rejection ratio U_{rr} between the fudemental and the undesired response. Larger the difference in frequency separation and amplitude of signal better is the reception in a receiver. This is found from the intercept point[3] and is shown in Fig. 3.

The graph gives the relationship between input power P_{in} versus output P_{out} response in dB of the receiver in question/analysis. *G* is the stage gain, U_{rr} defines a rejection ratio between the fundemental and the undesired response at the output stage. P_o is the level of desired output response at frequency f_d in dB. Fundamental and the undesire response have a slope of *l*, and *m* respectively. Ip_o is the output responses at intercept point, *d* is the difference in output level intercept point. Ip_o and U_{rr} are the difference in power level between f_d, and f_u at the output stage.

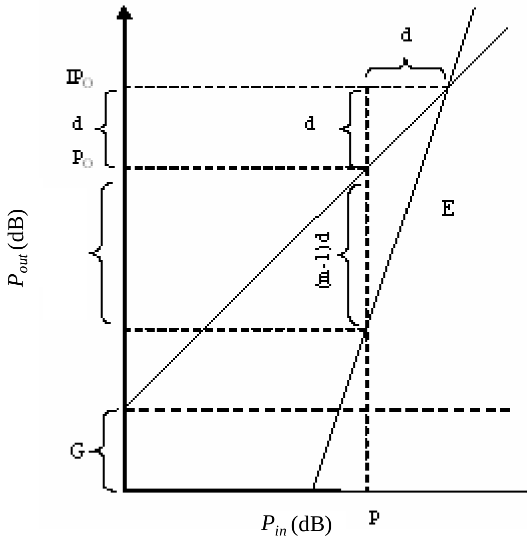

Figure 3. Intercept point and undesired response.

5. INFERENCE SIMULATION MODEL

A mobile radio interference simulation model[4] is illustrated in Fig. 4. Various operating simulation and operating distances are shown in Tables 1and 2, respectively. Situation 1 is more severe to produce multiple mixing of carriers and their harmonics to increase the vehicle EM ambient, while situations 2 to 4 are severe from the point of view of receiver performance. Comparatively, situations 5 to 7 are less severe while other factors such as cable coupling, intra-system emitters, etc. degrading the receiver's performance cannot be ruled out. Operating distances are chosen for the most practical situation the vehicle may encounter.

System noise factor model according to Longley-Rice[5] for the battlefield scenario can be taken as

$$P_N = -174 + F_a - 10\log_{10}{}^{B} \qquad (1)$$

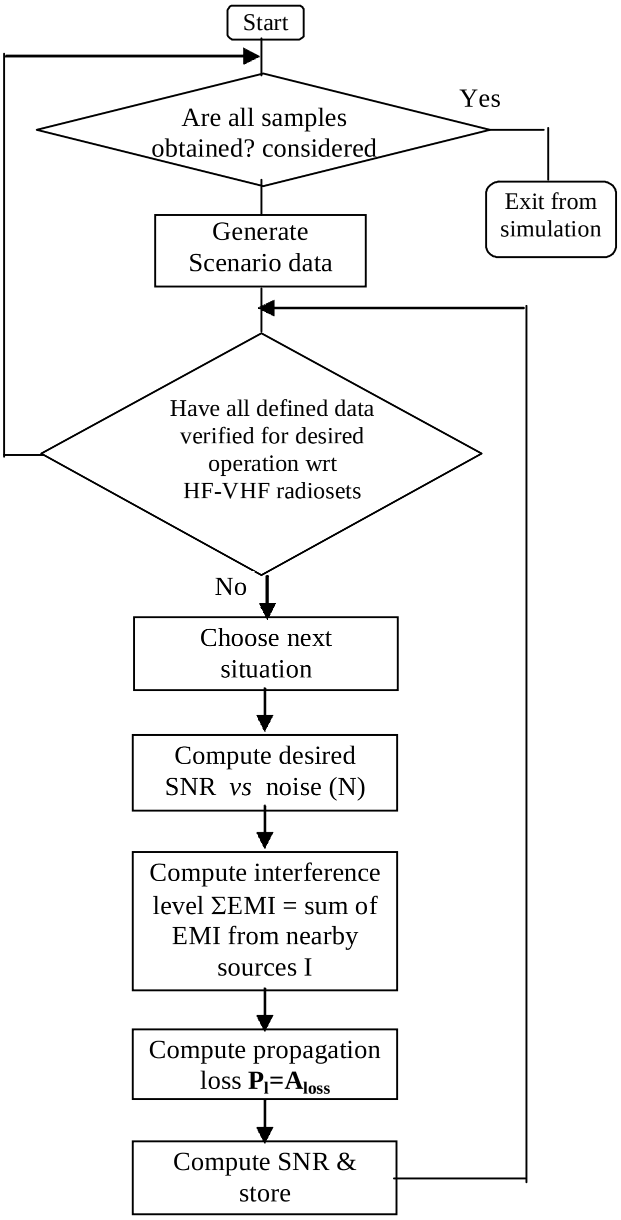

Figure 4. Mobile radio interference simulation.

Table 1. Operating situations

HF	T_X	T_X	T_X	R_X	T_X	R_X	R_X	R_X
VHF-I	T_X	T_X	R_X	T_X	R_X	R_X	T_X	R_X
VHF-II	T_X	R_X	T_X	T_X	R_X	T_X	R_X	R_X
Situation No.	1	3	4	5	6	7	8	2

Table 2. Operating distances

Type of radio	Frequency range (MHz)	Nearest distance of radio	Farthest distance of radio	Transmitter RF power (W)	Freq. Desig- nation
HF	1.6-30	10 km	50 km	100	f_1
VHF-I	30-88	500 m	30 km	50	f_2
VHF-II	30-88	1000 m	30 km	50	f_3

where B the bandwidth/channel spacing is taken as 25 kHz for VHF radio and 10 kHz for HF radio.

$$\text{where } F_a = (dB) = 41.09 - 10.87\log_{10} f \text{ MHz} \qquad (2)$$

F_a can be computed for 1.6 MHz to 88 MHz both for HF and VHF radios.

P_N the environmental noise power level in dBm is computed for 1.6 MHz to 88 MHz from the value of F_a and chosen 'B'. Received signal P_R is computed from

$$P_R = P_T + G_1 + G_2 - A_{LOSS} \qquad (3)$$

where P_T is transmitted power in dB. G_1, G_2 being gain of transmit and receive antennae while A_{Loss} is the propagation loss.

CNR in dB is calculated as

$$P_R - P_N \qquad (4)$$

for the total spectrum.

In calculating CNR, only noise due to environment is taken here as an illustrative example whereas additive noise due to EMI within the vehicle and external jamming signal levels are also to be included for the exact simulation. From the resulting CNR correlated to power ratio

$$CNR_{PR} = 10^x \qquad (5)$$

where $x = [CNR_{\mathrm{dB/10}}]$.

The probability of successful communication

$$[P_c = 1 - P_e] \qquad (6)$$

for the simulation under consideration can be arrived at, where P_c is the .probability of successful communication and P_e is the probability of loss of communication due to noise. P_e in the presence of fast fading can be found out from the following equation

$$P_e = \left[\frac{1}{2\left(1 + \frac{CNRPR}{2}\right)^m} \right] \qquad (7)$$

where m is the order of diversity and in this case m=1 [no diversity] and P_e= 6.2 x $10^{-3,}$ which is approximately 6 per cent.

When the received power P_r becomes closer to equivalent noise level P_n, the CNR becomes small and consequently CNR_{PR} is also less, and hance, P_e becomes large, meaning that the probability of successful communication has been reduced and loss of communication has been increased to high percentage, say 25 per cent/or even more.

A_{Loss} = Propagation loss which is defined by the equation according to Egli Emperical model[6] is given as

$$L_b = 88 + 20\log_{10} f_{MHz} + 20\log_{10} hth_r + 40\log_{10} d \qquad (8)$$

where h_t, h_r the height of transmitting and receiving antennas from ground are in meters and d = distance in km. Calculating L_b for 1.6 MHz to 88 MHz with appropriate distance, one can use that figure for computing P_r.

Next the interference level from various sources (namely VHF and HF transmitters) reaching the HF and VHF receivers are to be considered. Here, the HF harmonics from distant transmitter are significant whereas for VHF receiver, VHF fundamental emissions from nearby radio sets in the frontal area are sources of EMI (other than intended receiver-tuned signal).One can say that one *HF* frequency and two VHF frequencies at 500 m-1 km is the shortest distance, the VHF receiver located midway between two vehicles may encounter. For the 500 m station, harmonics are important. For harmonics levels at victim receiver, either measured value or MILStd-461C data[7] can be used. As a sample case EMI frequencies and levels are calculated for the VHF receiver located midway as shown in Fig. 5

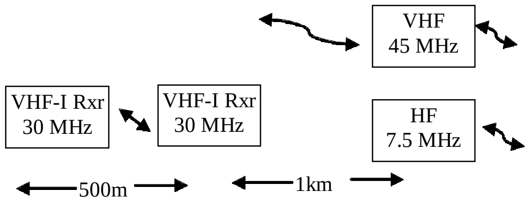

Figure 5. Radio set deployment diagram.

Receiver frequency f_o = 30 MHz

1st transmitter harmonics (500 m) = 60 MHz, 90 MHz and second VHF frequency 45 MHz (1 km) and its harmonics being strong signals from the nearby vehicles.

2nd transmitter fundamental (1km) = HF frequency and its harmonics say 7.5 MHz, 15 MHz, 22.5 MHz, 30 MHz, 37.5 MHz, 45 MHz.

Receiver third-order intermodulation is the most severe situation and IMI power is calculated from

$$P_e = -93 + 2P_n + P_f - 60\log\Delta f\,(\%) \qquad (9)$$

where P_e = equivalent input power (dBm)

P_n = power of nearest carrier signal (dBm)

P_f = power of farthest carrier signal (dBm)

Δf (%)= frequency separation between the nearbycarrier and the receiver-tuned frequency percentage

$$= \frac{|f_{OR} - f_N|}{f_{OR}} \times 100 \qquad (10)$$

Using the above formulae, intermodulation interference (IMI) was analysed for the given situation. For two sets of pairs of HF-VHF carrier frequencies [(28,30)(29,32)], and six sets of VHF-VHF carrier frequencies [(30,32)(46,48)(86,888) and (36,44) (48,50) (80,78)] P_e was computed with Δ_f ranging from 2.3 per cent to 10.3 per cent which are more practical situations. Fig. 11 gives the receiver third-order inter modulation power.

6. SIMULATION RESULTS

Table 3 gives the consolidated simulation data and Table 4 gives the computed/simulated test results. From the results, it is seen that the number of channels affected/denied and the number of channels available [min and max] for operations along with minimum frequency separation required for a safe and reliable operation were evolved. Finally, the spectral efficiency for all these radio sets were computed for a given situation. It may differ wrt to number of jamming sources in actual usage and the deployed area scenario. Detailed computations of receiver performance figures and noise margins are graphically shown in [in Figs 6 to 13].

FIM of HF and VHF radio sets computed for various ractical communication ranges wrt operational situations are illustrated in Figs 12 and 13, respectively

Figure 6 indicates the pattern of P_n environmental noise factor [system model for battlefield scenario] for HF

Table 3. Simulation data

Type of radio and frequency range	**Δf_{min} Δf_{max}**	**Transmitter power**		**R_x sensitivity**	**System noise f_a (dB)**		**FIM * (dB)**
		P_l	**P_h**	**P_r (dBm)**	**min**	**max**	**Min-max**
HF 1.6-30 MHz SSB / AM	1000 Hz 28.4 MHz	5 W	100 W	-107	25	38	61.5 to 181.5
VHF I 30-88 MHz FM	25 KHz 58 MHz	250 mW 500 mW	50 W	-115	20	25	61.6 to 157
VHF II 30-88 MHz FM	25 KHz 58 MHz	do	do	-115	20	25	-do-

Note: *Fundamental interference margin (FIM) is calculated from $FIM = -32 + 2\log_{10} F_{MHz} + 20\log_{10} d_{km}$

Table 4. Computed/simulation results

Propagation loss for D_{min} (dB)	Propagated loss for D_{max} (dB)	No. of channels affected	No. of channels available**		Remarks	
			min	max	%Δf	OS_{eff}
88-110	100-128	994	1846	2840	5	65%
90-95	128-135	696	1624	2320	2.5	70%
90-95	128-135	696	1624	2320	2.5	70%

Note**Max. Channels refer to manufacturer's data while min. channels refer to EMI-free options available.

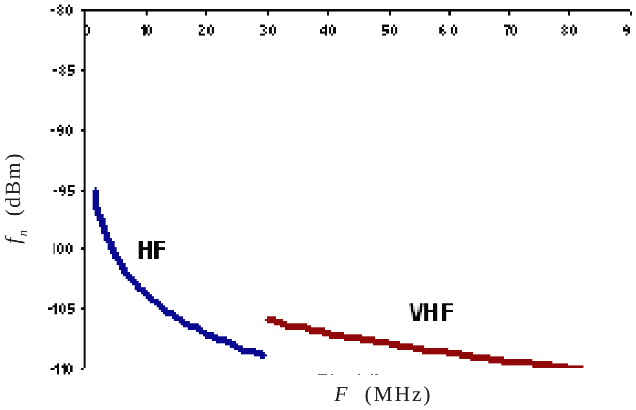

Figure 6. Environmental noise (HF, VHF).

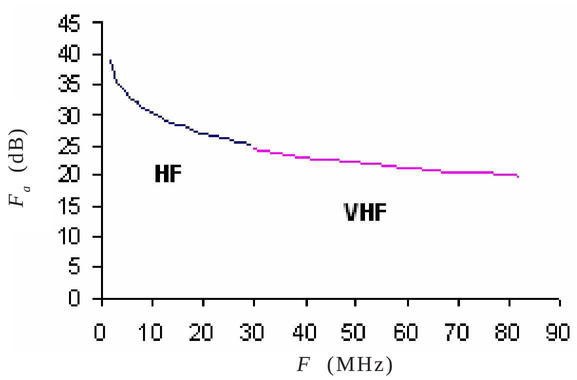

Figure 7. System noise factor (HF, VHF).

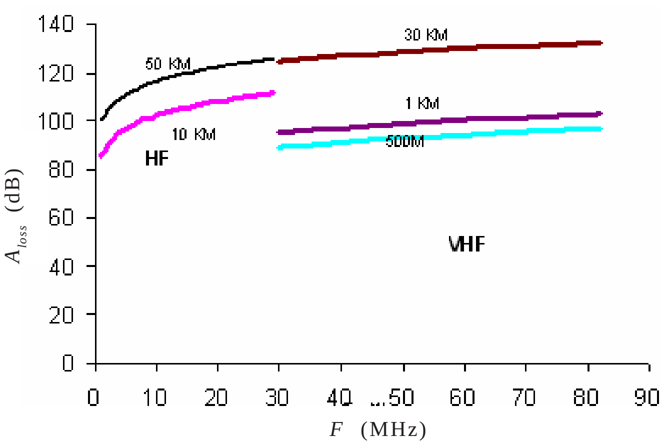

Figure 8. Propagation loss (HF, VHF).

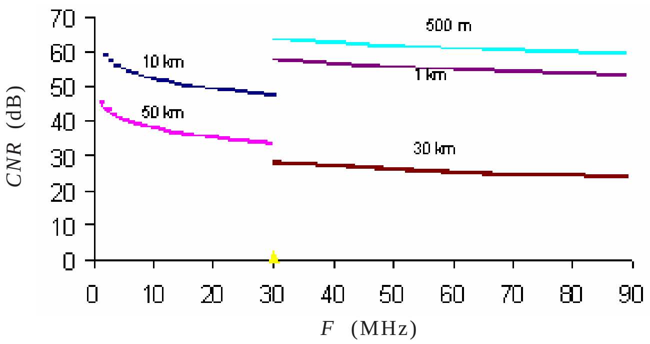

Figure 9. CNR vs frequency (HF, VHF).

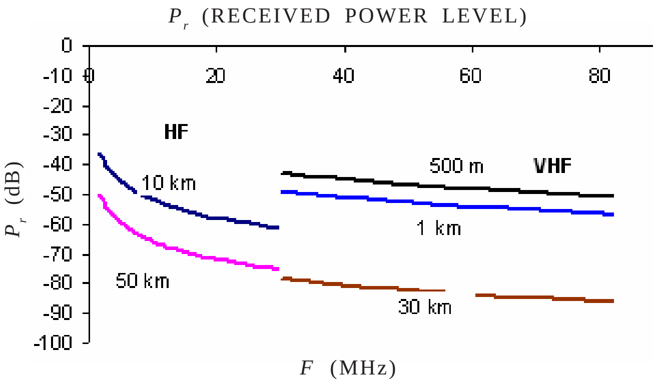

Figure 10. Received power level (HF, VHF).

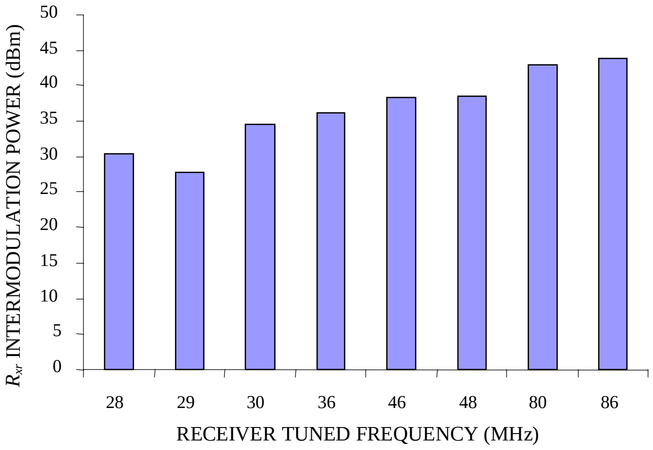

Figure 11. R_{xr} inter-modulation power.

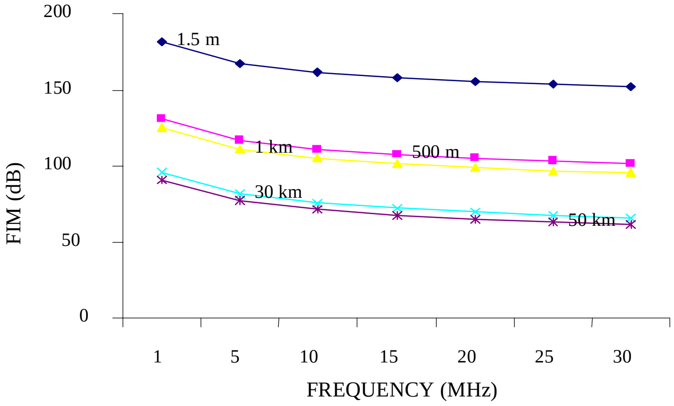

Figure 12. FIM for HF radio set.

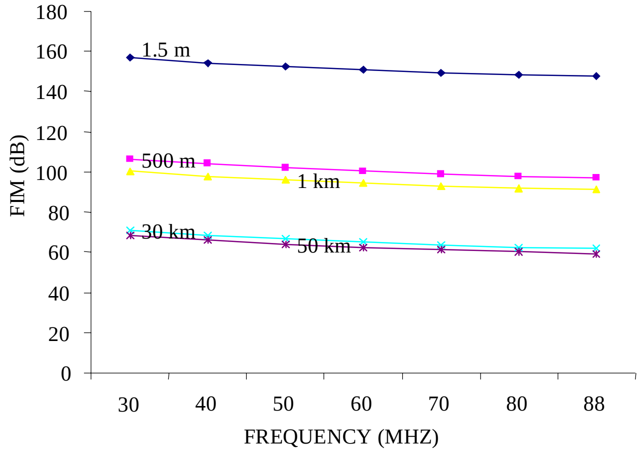

Figure 13. FIM for VHF radio set.

and VHF radio sets and Fig.7 indicates the behaviour of noise factor as a function of carrier frequency alone which has similar pattern to system noise factor as exponential fall.

Propagation loss computed for various practical communication ranges wrt operational requirements in the HF and VHF regions are illustrated in Fig. 8. This clearly indicates that it is an exponential rise for HF frequencies and fairly a linear response for VHF frequencies.

As propagation loss increases wrt frequencies, the CNR falls in replica [Fig. 9]. It is found that CNR is falling rapidly as frequency increases in HF and steadily at VHF. This is true for smaller ranges to higher ranges also.

Received power level variations for HF and VHF radio sets are indicated in Fig 10 for 1 MHz to 88 MHz at various ranges considered for the operational situations/requirements. As already explained in Section 5, receiver third-order intermodulation power is shown in Fig.11. This can be exploited further for various frequency separations in HF and VHF/UHF radio sets for the benefit of avoiding IMI frequencies.

7. CONCLUSION

A methodology to simulate the performance of mobile radio system comprising three radio sets (VHF-2 and one HF) has been addressed. Channel-denial concept is the basic performance measure and number of channels denied on account of EMI, inter modulation and undesired response are briefly accounted. Various parameters responsible for performance are computed for the given situations, which can be modified to compute further complex problems. Three radio set is the ultimate in vehicular platforms beyond which performance degradation is likely to be very severe.

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REFERENCES

1. Lee, William C.Y. *et al.* A computer simulation model for the evaluation of mobile radio system with the military tactical environmental. *IEEE Trans. Vehic. Technol*. 1983, **32**, 177-90.
2. Lee, W. C. Y. Mobile communication engineering. McGraw-Hill publication, New York
3. Sagers Richard, C. Intercept points and undesired responses. *IEEE Transactions*, July1983, 121-33
4. Asrar Sheikls, U.H. Wireless communication theory and techniques. Kluwer Academic Publisher, 2004.
5. Reinaldo, Perez. Wireless communications design handbook, Academic Press, 1998, **2**.
6. Duff, William, G. A handbook on mobile communications. Don White Consultants Inc:
7. Duff, William, G. EMC design of telecommunications systems. EMC Expo., 1986.

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