## REFERENCES

Aggarwal, K. R. (1974). Some higher class PBIB designs and their application as confounded factorial experiments. Ann. Inst. Statist. Math. 26, 315-323.
Bailey, R. A. (1977). Patterns of confounding in factorial designs. Biometrika 64, 597-603.

Bailey, R. A. (1985a). Balance, orthogonality and efficiency factors in factorial designs. J. R. Statist. Soc. B47, 453-458.
Bailey, R. A. (1985b). Factorial designs and abelian groups. Linear Algebra and Appl. 70, 349-368.

Bailey, R. A., Gilchrist, F. M. L. and Patterson, H. D. (1977). Identification of effects and confounding patterns in factorial designs. Biometrika 64, 347-354.

Bhargava, R. P. (1980). A property of Jackknife estimation of the variance when more than one observation is omitted. Technical Report 140, Stanford University, Department of Statistics.

Bose, R. C. (1947). Mathematical theory of the symmetrical factorial design. Sankhya 8, 107-166.
Bose, R. C. and Kishen, K. (1940). On the problem of confounding in general symmetrical factorial design. Sankhya 5, 21-36.
Bose, R. C. and Shrikhande, S. S. (1960). On the composition of balanced incomplete block designs. Can. J. Math. 12, 177-188.
Bose, M. and Mukerjee, R. (1987). Factorial designs for quality-quantity interaction. Calcutta Statist. Assoc. Bull. 36, 141-152.

Bourke, P. D. (1981). On the analysis of some multivariate randomized response designs for categorical data. J. Statist. Plann. Inf. 5, 165-170.
Box, G. E. P. and Draper, N. R. (1987). Empirical Model Building and Response Surfaces. John Wiley: New York.
Chatterjee, K. and Mukerjee, R. (1986). Some search designs for symmetric and asymmetric factorials. J. Statist. Plann. Inf. 13, 357-363.
Chatterjee, S. K. (1982). Some recent developments in the theory of asymmetric factorial experiments - a review. Sankhya A44, 103-113.

Chauhan, C. K. (1987). Some results on regularity in a single replicate design. Commun. Statist. - Theor. Meth. 16, 2263-2268.

Chauhan, C. K. (1988). On partial regularity in single replicate factorial
experiments. Utilitas Math. 33, 205-210.
Chauhan, C. K. and Dean, A. M. (1986). Orthogonality of factorial effects. Ann. Statist. 14, 743-752.
Cheng, C. S. and Wu, C. F. (1980). Balanced repeated measurements designs. Ann. Statist. 8, 1272-1283.

Collings, B. C. (1984). Generating the intrablock and interblock subgroups for confounding in general factorial experiments. Ann. Statist. 12, 1500-1509.

Cottor, S. C. (1974). A general method of confounding in symmetric factorial exeriments. J. R. Statist. Soc. B36, 267-276.
Cottor, S. C., John, J. A. and Smith, T. M. F. (1973). Multi-factor experiments in non-orthogonal designs. J. R. Statist. Soc. B35, 361-367.

Das, M. N. (1960). Fractional replicates as asymmetrical factorial designs. J. Indian Soc. Agric. Statist. 12, 159-174.
Das, M. N. (1964). A somewhat alternative approach for construction of symmetrical factorial designs and obtaining maximum number of factors. Calcutta Statist. Assoc. Bull. 18, 1-17.
Das, M. N. and Giri, N. C. (1986). Design and Analysis of Experiments. Second Edition. Wiley Eastern: New Delhi.
David, H. A. and Wolock, F. W. (1965). Cyclic designs. Ann. Math. Statist. 36, 1526-1534.
Dean, A. M. (1978). The analysis of interactions in single replicate generalized cyclic designs. J. R. Statist. Soc. B40, 79-84.
Dean, A. M. and John, J. A. (1975). Single replicate factorial experiments in generalized cyclic designs II. Asymmetrical arrangements. J. R. Statist. Soc. B37, 72-76.
Dean, A. M. and Lewis, S. M. (1980). A unified theory of generalized cyclic designs. J. Statist. Plann. Inf. 4, 13-23.

Dean, A. M. and Lewis, S. M. (1983). Upper bounds for average efficiency factors of two-factor interactions. J. R. Statist. Soc. B45, 252-257.
Dean, A. M. and Lewis, S. M. (1984). Disconnected generalized cyclic designs. Ohio State University Technical Report 298.
Dean, A. M. and Lewis, S. M. (1986). A note on the connectivity of generalized cyclic designs. Commun. Statist. - Theor. Meth. 15, 3429-3433.
Dey, A. (1985). Orthogonal Fractional Factorial Designs. Wiley Eastern: New Delhi.

Efron, B. and Stein, C. (1981). The jackknife estimate of variance. Ann. Statist. 9, 586-596.

El Mossadeq, A., Kobilinksy, A. and Collombier, D. (1985). Construction d'orthogonaux dans les groupes abeliens finis eet confusions d'effects dans les plans factoriels. Linear Algebra and Appl. 70, 303-320.
Federer, W. T. (1955). Experimental Design: Theory and Application. The Macmillan Company: New York.
Federer, W. T. (1980). Some recent results in experimental design with a bibliography. Internat. Statist. Rev. 48, 357-368.
Federer, W. T. and Zelen, M. (1966). Analysis of multifactor classifications with unequal number of observations. Biometrics 22, 526-552.

Fisher, R. A. (1935). The Design of Experiments. Oliver and Boyd: London.
Fisher, R. A. and Yates, F. (1963). Statistical Tables for Biological Agricultural and Medical Research (6th edition). Oliver and Boyd: Edinburgh.
Fletcher, D. J. and John, J. A. (1985). Change over designs and factorial structure. J. R. Statist. Soc. B47, 117-124.

Giovagnoli, A. (1977). On the construction of factorial designs using abelian group theory. Rend. Sem. Mat. Univ. Padova 58, 195-206.
Gupta, S. C. (1983a). A basic lemma and the analysis of block and Kronecker product designs. J. Statist. Plann. Inf. 7, 407-416.
Gupta, S. C. (1983b). Some new methods for constructing block designs having orthogonal factorial structure. J. R. Statist. Soc. B45, 297-307.
Gupta, S. C. (1985). On Kronecker block designs for factorial experiments. J. Statist. Plann. Inf. 11, 227-236.
Gupta, S. C. (1986a). Interaction efficiencies in Kronecker block designs. J. Statist. Plann. Inf. 14, 275-279.
Gupta, S. C. (1986b). Efficiency consistency in designs. Commun. Statist. - Theor. Meth. 15, 1315-1318.
Gupta, S. C. (1986c). Factorial experiments in four-associate class cyclic PBIB designs. Calcutta Statist. Assoc. Bull. 35, 17-24.
Gupta, S. C. (1987a). A note on component-wise Kronecker designs. Metrika 34, 283-286.

Gupta, S. C. (1987b). On designs for factorial experiments derivable from generalized cyclic designs. Sankhya B49, 90-96.
Gupta, S. C. (1987c). Generating generalized cyclic designs with factorial balance. Commun. Statist. - Theor. Meth. 16, 1885-1900.
Gupta, S. (1988). The association matrices of extended group divisible scheme. J. Statist. Plann. Inf. 20, 115-120.
Gupta, S. and Mukerjee, R. (1989). Efficient non-equireplicate designs obtained by merging of treatments. Comp. Statist. \& Data Analy. 8, (to appear).
Habermann, S. J. (1974). The Analysis of Frequency Data. The University of Chicago Press: Chicago.
Habermann, S. J. (1975). Direct products and linear models for complete factorial tables. Ann. Statist. S, 314-333.
Hinkelmann, K. and Kempthorne, O. (1963). Two classes of group divisible partial diallel crosses. Biometrika 50, 281-291
Jarret, R. G. and Hall, W. B. (1978). Generalized cyclic incomplete block designs. Biometrika 65, 397-401.
John, J. A. (1966). Cyclic incomplete block designs. J. R. Statist. Soc. B28, 345-360.
John, J. A. (1973a). Factorial experiments in cyclic designs. Ann. Statist. 1, 188-194.
John, J. A. (1973b). Generalized cyclic designs in factorial experiments. Biometrika 60, 55-63.
John, J. A. (1981). Factorial balance and the analysis of designs with factorial structure. J. Statist. Plann. Inf. 5, 99-105.
John, J. A. (1987). Cyclic Designs. Chapman and Hall: New York.
John, J. A. and Dean, A. M. (1975). Single replicate factorial experiments in generalized cyclic designs I. Symmetrical arrangements. J. R. Statist. Soc. B97, 63-71.
John, J. A. and Lewis, S. M. (1983). Factorial experiments in generalized cyclic rowcolumn designs. J. R. Statist. Soc. B45, 245-251.
John, J. A. and Quenouille, M. H. (1977). Experiments: Design and Analysis. Oliver and Boyd: London.
John, J. A. and Smith, T. M. F. (1972). Two-factor experiments in non-orthogonal designs. J. R. Statist. Soc. B34, 401-409.
John, J. A., Wolock, F. W. and David, H. A. (1972). Cyclic Designs. National Bur. Standards Appl. Math. Ser. 62.

John, P. W. M. (1971). Statistical Design and Analysis of Experiments. The Macmillan Company: New York.
Jones, B. (1980). Combining two component designs to form a row-and- column design. Appl. Statist. 29, 334-337.
Karlin, S. and Rinott, Y. (1982). Applications of ANOVA-type decompositions for comparisons of conditional variance statistics including jackknife estimates. Ann. Statist. 10, 485-501.
Kempthorne, O. (1952). The Design and Analysis of Experiments. John Wiley: New York.
Khatri, C. G. and Rao, C. R. (1968). Solutions to some functional equations and their applications to characterization of probability distributions. Sankhya A30, 167-180.

Kiefer, J. C. (1975). Construction and optimality of generalized Youden Designs. A Survey of Statistical Design and Linear Models (J. N. Srivastava ed.). North Holland: Amsterdam, 333-353.
Kishen, K. (1958). Recent developments in experimental design. Presidential Address to the Section of Statistics of the 45th Indian Science Congress, Madras.
Kishen, K. and Srivastava, J. N. (1959). Mathematical theory of confounding in asymmetrical and symmetrical factorial designs. J. Indian Soc. Agric. Statist. 21, 73-110.

Kishen, K. and Tyagi, B. N. (1963). Partially balanced asymmetrical factorial designs. Contributions to Statistics. Presented to Professor P. C. Mahalanobis on his 70th birthday. Pergamon Press, New York, 147-158.

Kishen, K. and Tyagi, B. N. (1964). On the construction and analysis of some balanced asymmetric factorial designs. Calcutta Statist. Assoc. Bull. 18, 123-149.

Kramer, C. Y. and Bradley, R. A. (1957). Intrablock analysis for factorial in two associate class group divisible designs. Ann. Math. Statist. 28, 349-361.
Kshirsagar, A. M. (1966). Balanced factorial designs. J. R. Statist. Soc. B28, 559569.

Kurkjian, B. and Zelen, M. (1962). A calculus for factorial arrangements. Ann. Math. Statist. 39, 600-619.
Kurkjian, B. and Zelen, M. (1963). Applications of the calculus for factorial arrangements. I. Block and direct product designs. Biometrika 50, 63-73.

Kuwada, M. and Nishii, R. (1988). On the characteristic polynomial of the information matrix of balanced fractional $s^{m}$ factorial designs of resolution $V_{p, q}$. J. Statist Plann. Inf. 18, 101-114.
Lewis, S. M. (1982). Generators for asymmetrical factorial experiments. J. Statist. Plann. Inf. 6, 59-64.
Lewis, S. M. (1986). Composite generalized cyclic row-column designs. Sankhya B48, 373-379.
Lewis, S. M. and Dean, A. M. (1980). Factorial experiments in resolvable generalized cyclic designs. B. I. A. S. 7, 159-167.
Lewis, S. M. and Dean, A. M. (1984). Upper bounds for factorial efficiency factors. J. R. Statist. Soc. B46, 273-278.

Lewis, S. M. and Dean, A. M. (1985). A note on efficiency consistent designs. J. R. Statist. Soc. B47, 261-262.
Lewis, S. M. and Dean, A. M. and Lewis, P. H. (1983). Single replicate designs for two factor experiments. J. R. Statist. Soc. B45, 224-227.
Lewis, S. M. and Tuck, M. G. (1985). Paired comparison designs for factorial experiments. Appl. Statist. 34, 227-234.
Magda, C. (1980). Circular balanced repeated measurements designs. Commun. Statist. - Theor. Meth 9, 1901-1918.
Mathews, G. B. (1892). The Theory of Numbers. Bell: Cambridge.
Mukerjee, R. (1979). Inter-effect orthogonality in factorial experiments. Calcutta Statist. Assoc. Bull. 28, 83-108.
Mukerjee, R. (1980). Further results on the analysis of factorial experiments. Calculutta Statist. Assoc. Bull. 29, 1-26.
Mukerjee, R. (1981a). Construction of effectwise orthogonal factorial designs. J. Statist. Plann. Inf. 5, 221-229.
Mukerjee, R. (1981b). Inference on confidential characters from survey data. Calcutta Statist. Assoc. Bull. 30, 77-88.
Mukerjee, R. (1982). Construction of factorial designs with all main effects balanced. Sankhya B44, 154-166.
Mukerjee, R. (1984). Applications of some generalizations of Kronecker product in the construction of factorial designs. J. Indian Soc. Agric. Statist. 36, 3846.

Mukerjee, R. (1985). Fraction selection problem in discrete muiltivariate analysis.

Sankhya A47, 350-356.
Mukerjee, R. (1986). Construction of orthogonal factorial designs controlling interaction efficiencies. Commun. Statist. - Theor. Meth. 15, 1535-1548.
Mukerjee, R. and Bose, M. (1988a). Estimability consistency and its equivalence with regularity in factorial designs. Utilitas Math. 33, 211-216.
Mukerjee, R. and Bose, M. (1988b). Non-equireplicate Kronecker factorial designs. J. Statist. Plann. Inf. 19, 261-267.
Mukerjee, R. and Bose, M. (1989). Admissibility in factorial designs. Commun. Statist.-Theor. Meth. (to appear).
Mukerjee, R. and Dean, A. M. (1986). On the equivalence of efficiency- consistency and orthogonal factorial structure. Utilitas Math. 30, 145-151.
Mukerjee, R. and Huda, S. (1988). Optimal design for the estimation of variance components. Biometrika 75, 75-80.
Mukerjee, R. and Sen, M. (1988). Kronecker factorial designs for multiway elimination of heterogeneity. Ann. Inst. Statist. Math. 40, 195-210.
Muller, E. R. (1966). Balanced confounding of factorial experiments. Biometrika 53, 507-524.

Nair, K. R. and Rao, C. R. (1941). Confounded designs for asymmetrical factorial experiments. Science and Culture 7, 313-314.
Nair, K. R. and Rao, C. R. (1942). Confounded designs for $k \times p^{m} \times q^{n} \times \cdots$ type factorial experiments. Science and Culture 7, 361-362.

Nair, K. R. and Rao, C. R. (1948). Confounding in asymmetric factorial experiments. J. R. Statist. Soc. B10, 109-131.
Nelder, J. A. (1965). The analysis of randomized experiments with orthogonal block structure. I. Block structure and the null analysis of variance. Proc. R. Soc. A283, 147-162.
Paik, U. B. and Federer, W. T. (1973). Partially balanced designs and properties A and B. Commun. Statist. - Theor. Meth. 1, 331-350.
Paik, U. B. and Federer, W. T. (1974). Analysis of non-orthogonal n-way classifications. Ann. Statist. 2, 1000-1021.
Patterson, H. D. (1965). The factorial combination of treatments in rotation experiments. J. Agric. Sci. 65, 171-182.

Patterson, H. D. (1976). Generation of factorial designs, J. R. Statist. Soc. B38, 175179.

Patterson, H. D. and Bailey, R. A. (1978). Design keys for factorial experiments. Appl. Statist. 27, 335-343.
Pearce, S. C. (1971). Precision in block experiments. Biometrika 58, 161-167.
Puri, P. D. and Nigam, A. K. (1975). A note on efficiency balanced designs. Sankhya B97, 457-460.
Puri, P. D. and Nigam, A. K. (1976). Balanced factorial experiments I. Commun. Statist. - Theor. Meth. 5, 599-619.
Puri, P. D. and Nigam, A. K. (1978). Balanced factorial experiments II. Commun. Statist. - Theor. Meth. 7, 591-605.

Puri, P. D. and Nigam, A. K. (1983). Merging of treatments in block designs. Sankhya B45, 50-59.

Raghavarao, D. (1971). Constructions and Combinatorial Problems in Design of Experiments. John Wiley: New York.
Raktoe, B. L. (1969). Combining elements from distinct finite fields in mixed factorials. Ann. Math. Statist. 40, 498-504.
Raktoe, B. L. (1970). Generalized combining of elements from finite fields. Ann. Math. Statist. 41, 1763-1767.
Raktoe, B. L., Hedayat, A. and Federer, W. T. (1980). Factorial Designs. John Wiley: New York.
Raktoe, B. L., Rayner, A. A. and Chalton, D. O. (1978). On construction of confounded mixed factorial and lattice designs. Austral. J. Statist. 20, 209-218.
Rao, C. R. (1956). A general class of quasi-factorial and related designs. Sankhya 17, 165-174.
Rao, C. R. (1973a). Linear Statistical Inference and its Applications. Second Edition. John Wiley: New York.
Rao, C. R. (1973b). Some combinatorial problems of arrays and applications to design of experiments. A Survey of Combinatorial Theory, J. N. Srivastava ed. North Holland: Amsterdam, 349-359.
Rao, C. R. and Mitra, S. K. (1971). Generalized Inverse of Matrices and its Applications. John Wiley: New York.
Roberts, A. W. and Verlag, D. E. (1973) Convex Functions. Academic Press: New York.
Sardana, M. G. and Das, M. N. (1965). On the construction and analysis of some
confounded asymmetrical factorial designs. Biometrics 21, 948-956.
Sen, M. and Mukerjee, R. (1987). Optimal repeated measurements designs under interaction. J. Statist. Plann. Inf. 17, 81-91.
Shah, B. V. (1958). On balancing in factorial experiments. Ann. Math. Statist. 29, 766-779.

Shah, B. V. (1960a). Balanced factorial experiments. Ann. Math. Statist. 31, 502514.

Shah, B. V. (1960b). On a $5 \times 2^{2}$ factorial design. Biometrics 16, 115-118.
Sihota, S. S. and Banerjee, K. S. (1981). On the algebraic structures in the construction of confounding plans in mixed factorial designs on the lines of White and Hultquist. J. Amer. Statist. Assoc. 76, 996-1001.

Smith, H. J. S. (1861). On systems of linear indeterminate equations and congruences. Proc. R. Soc. London 11, 87-89.

Srivastava, J. N. (1978). A review of some recent work on discrete optimal factorial designs for statisticians and experimenters. Developments in Statistics, Vol. 1, 267-329. Academic Press: New York.
Srivastava, J. (1987). On the inadequancy of customary orthogonal arrays in quality control in general scientific experimentation and the need of probing designs of higher revealing power. Commun. Statist. - Theor. Meth. 16, 2901-2941.

Street, A. P. and Street, D. J. (1987). Combinatorics of Experimental Design. Claredon Press: New York.

Street, D. J. (1986). A survey of construction methods for single replicate factorial designs. Ars Combinatoria 21A, 147-168.
Suen, C. -Y. and Chakravarti, I. M. (1986). Efficient two-factor balanced designs. J. R. Statist. Soc. B48, 107-114.

Takemura, A. (1983). Tensor analysis of anova decomposition. J. Amer. Statist. Assoc. 78, 894-900.
Tharthare, S. K. (1965). Generalized right angular designs. Ann. Math. Statist. 36, 1535-1553.
Thomson, H. R. and Dick, I. D. (1951). Factorial designs in small blocks derivable from orthogonal Latin squares. J. R. Statist. Soc. B18, 126-130.
Tyagi, B. N. (1971). Confounded asymmetric factorial designs. Biometrics 27, 229 232.

Vartak, M. N. (1955). On an application of Kronecker product of matrices to statistical designs. Ann. Math. Statist. 26, 420-438.
Voss, D. T. (1986). On generalization of the classical method of confounding to asymmetric factorial experiments. Commun. Statist. - Theor. Meth. 15, 1299-1314.
Voss, D. T. (1986). First order deletion designs and the construction of efficient nearly - orthogonal factorial designs in small blocks. J. Amer. Statist. Assoc. 81, 813-818.
Voss, D. T. (1988). Single-generator generalized cyclic factorial designs as pseudofactor designs. Ann. Statist. 16, 1723-1726.
Voss, D. T. and Dean, A. M. (1985). Methods of confounding in single replicate designs. Tech. Rep. No. 318, Dept. of Statistics, Ohio State University.
Voss, D. T. and Dean, A. M. (1987). A comparison of classes of single replicate factorial designs. Ann. Statist. 15, 376-384.
Voss, D. T. and Dean, A. M. (1988). On confounding in single replicate factorial experiments, Utilitas Math. 33, 59-64.
White, D. and Hultquist, R. A. (1965). Construction of confounding plans for mixed factorial designs. Ann. Math. Statist. 36, 1256-1271.
Williams, E. R. (1975). A new class of resolvable block designs. Ph.D. thesis, Edinburgh University.
Williams, E. R. and Patterson, H. D. (1977). Upper bounds for efficiency factors in block designs. Austral. J. Statist. 19, 194-201.
Worthley, R. and Banerjee, K. S. (1974). A general approach to confounding plans in mixed factorial experiments when the number of levels of a factor is any positive integer. Ann. Statist. 2, 579-585.
Yates, F. (1937). The design and analysis of factorial experiments. Imperial Bureau of Soil Science. Technical Commun. No. 35.
Zelen, M. (1958). Use of group divisible designs for confounded asymmetric factorial experiments. Ann. Math. Statist. 29, 22-40.
Zelen, M. and Federer, W. T. (1964). Applications of the calculus for factorial arrangements II. Designs for two-way elimination of heterogeneity. Ann. Math. Statist. 35, 658-672.
Zelen, M. and Federer, W. T. (1965). Applications of the calculus for factorial arrangements III. Analysis of factorials with unequal numbers of
observations. Sankhya A 27, 383-400.

## INDEX

Admissibility, 108
Balanced, 9
with OFS, 10
Balanced confounded design, 11
Balanced factorial experiment, 11
Binary number association scheme, 18
BLUE, 8
Constrasts, 3
complete set of, 5
estimable, 8
mutually orthogonal, 4
normalized, 4
orthonormal, 4
Cyclic product, 81
Design:
admissible, 109
balanced confounded, 11
balanced with OFS, 10
bilinear classical, 94
connected, 8
cyclic, 48
deletion, 98
efficiency consistent, 43
EGD, 19
equireplicate, 7
estimability consistent, 47
general classical, 89
generalized cyclic, 51
generalized cyclic row-column, 66
GC/n, 52
having OFS, 8
having POFS, 37
having external POFS, 46
paired comparison, 55
partially efficiency-consistent, 46
partially regular, 42
property A, 15
regular, 32
$x$ - regular, 107
$x$ - super-regular, 107
Efficiency, 16-17
D-, A-, E-, 73
$\Phi_{p}-, 72-73$
EGD scheme, 18
association matrices, 19
Fractional GC set, 63
Generators of GC/n designs, 57
Khatri-Rao product, 79
Kronecker product, 5
componentwise, 75
ordinary, 73-74
Lexicographic order, 4
Matrix:
circulant, 30
permutation, 24
proper, 24
Merging of treatments, 100
Orthogonal factorial structure, 8
OFS, 8
and efficiency consistency, 45
and disconnected design, 36
and nonequireplicate designs, 84
partial, 37
structure $K$ and regularity, 34
Partial orthogonal factorial structure, 37
POFS, 37
of order $t, 39$
Property A, 11

## Set:

$\Omega, 4$
$\Omega(x), 44$
$\Omega(t), 40$
$\Omega^{*}, 11$
$\Omega_{g}^{*}, 75$
Structure $K, 24$
and OFS, 26
and regularity, 34
Symbolic direct product, 4

