

The Operational Calculus. II*

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III. Development of Heaviside's Rules

The development of certain transforms which are known in the literature of operational calculus as "Heaviside's rules" will now be undertaken. In the early history of the subject, there appears to have been much controversy over the subject, but when viewed from the Laplacian transform point of view, the proof of these powerful rules is seen to be most simple.

A. HEAVISIDE'S FIRST RULE

Heaviside's first rule is commonly known as "the partial fraction rule." This rule may be stated as follows:

If $g(p) = f(p)/F(p)$, where $f(p)$ and $F(p)$ are polynomials in p and the order of $F(p)$ is at least as high as the order of $f(p)$ and, further, the polynomial $F(p)$ has the n distinct zeros $p_1, p_2, \dots, p_n$. Then we have

$$f(p)/F(p) \doteq f(0)/F(0) + \sum_{r=1}^n \frac{F(p_r)e^{p_r t}}{p_r(dF/dp)_{p=p_r}}. \quad (59)$$

Proof:

By our general formula (1), we have, by the theory of residues,

$$\frac{f(p)}{F(p)} \doteq \sum \text{residues of } \frac{f(p)}{pF(p)}e^{pt}. \quad (60)$$

Now if $p_1, p_2, \dots, p_n$ are the n distinct zeros of $F(p)$, then we may write $F(p) = a(p-p_1)(p-p_2)\dots(p-p_n)$, where a is the coefficient of p^n .

The residue at $p=0$ is

$$\text{Limit } \frac{pf(p)e^{pt}}{pF(p)} = \frac{f(0)}{F(0)}, \quad (61)$$

and the residue at $p=p_r$ is

$$\begin{aligned} \text{Limit } \frac{(p-p_r)f(p)e^{pt}}{p_a(p-p_1)(p-p_2)\dots(p-p_r)\dots(p-p_n)} \\ = \frac{f(p_r)e^{p_r t}}{p_r(dF/dp)_{p=p_r}}. \end{aligned} \quad (62)$$

Hence, we have the Heaviside expansion theorem:

$$\frac{f(p)}{F(p)} \doteq \frac{f(0)}{F(0)} + \sum_{r=1}^n \frac{f(p_r)e^{p_r t}}{p_r(dF/dp)_{p=p_r}}. \quad (59)$$

B. HEAVISIDE'S SECOND RULE

$$\text{If } g(p) = \sum_{n=0}^{\infty} \frac{a_n}{p^n},$$

where the series on the right is a convergent series of negative powers of p , then

$$g(p) \doteq \sum_{n=0}^{\infty} a_n t^n / n! \quad (63)$$

This result is obtained by the term by term substitution of $t^n/n! \doteq 1/p^n$.

C. HEAVISIDE'S THIRD RULE

Heaviside's third rule concerns the transform of the series

$$g(p) = \sum_0^{\infty} a_n p^n + p^1 \sum_0^{\infty} b_n p^n,$$

where both series are convergent series in p .

By making use of the direct term by term application of the transform

$$1/p^r \doteq t^r / \Gamma(r+1) \quad (53)$$

and the facts that $\Gamma(1/2) = \sqrt{\pi}$ and $p^r \doteq 0$ when r is a positive integer, the transform

$$\begin{aligned} g(p) = a_0 + \frac{1}{(\pi t)^{1/2}} \left(b_0 - \frac{b_1}{2t} + \frac{1 \cdot 3 b_2}{(2t)^2} \right. \\ \left. - \frac{1 \cdot 3 \cdot 5 b_3}{(2t)^3} + \dots \right) \quad \text{for } t > 0. \end{aligned} \quad (64)$$

* This paper is the second of a series of three. The final part will appear in the May issue.

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Operational Calculus

A. P. Prudnikov, K.A. Skórník



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Operational Calculus and Generalized Functions Arthur Erdelyi, 2013-07-17 Based on a math course for advanced undergraduates and graduate students at Cal Tech this brief monograph requires a background in advanced calculus Topics include elementary and convergence theories of convolution quotients differential equations involving operator functions exponential functions of operators and problems in partial differential equations Includes solutions 1962 edition

Operational Calculus Jan Mikusinski, 2014-07-14 Pure and Applied Mathematics Volume 109 *Operational Calculus* Second Edition Volume I presents the foundations of operational calculus and its applications to physics and engineering This book introduces the operators algebraically as a kind of fractions Organized into three parts this volume begins with an overview of the concept as well as the characteristics of a convolution of continuous functions This text then examines the transitivity associativity and distributivity of convolution with regard to addition Other parts consider the methods of solving other difference equations particularly in the field of electrical engineering in which the variable runs over integer values only This book discusses as well the solution of differential equations under given initial conditions The final part deals with the characteristic properties of a derivative and provides the definition of algebraic derivative to any operators This book is a valuable resource for physicists electrical engineers mathematicians and research workers

Heaviside's Operational Calculus as Applied to Engineering and Physics Ernst Julius Berg, 1929

Integral Transformations, Operational Calculus and Their Applications Hari Mohan Srivastava, 2021-01-20 This volume consists of a collection of 14 accepted submissions including several invited feature articles to the Special Issue of MDPI's journal *Symmetry* on the general subject area of integral transformations operational calculus and their applications from many different parts around the world The main objective of the Special Issue was to gather review expository and original research articles dealing with the state of the art advances in integral transformations and operational calculus as well as their multidisciplinary applications together with some relevance to the aspect of symmetry Various families of fractional order integrals and derivatives have been found to be remarkably important and fruitful mainly due to their demonstrated applications in numerous diverse and widespread areas of mathematical physical chemical engineering and statistical sciences Many of these fractional order operators provide potentially useful tools for solving ordinary and partial differential equations as well as integral differintegral and integro differential equations fractional calculus analogues and extensions of each of these equations and various other problems involving special functions of mathematical physics and applied mathematics as well as their extensions and generalizations in one or more

variables

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On the Heaviside Operational Calculus Albert Huntoon Wait, 1926 [Introduction To The Operational Calculus](#) Lothar Berg, 2013-07-19 Introduction to the Operational Calculus is a translation of *Einführung in die Operatorenrechnung* Second Edition This book deals with Heaviside's interpretation on the Laplace integral and on Jan Mikusinski's fundamental work Operational Calculus Throughout the book basic algebraic concepts appear as aids to understanding some relevant points of the subject An important field for research in analysis is asymptotic properties This text also discusses examples to show the potentialities in applying operational calculus that run beyond ordinary differential equations with constant coefficients In using operational calculus to solve more complicated problems than those of ordinary differential equations with constant coefficients the concept of convergence assumes a significant role in the field of operators This book also extends the Laplace transformation and applies it to non transformable functions This text also presents three methods in which operational calculus can be modified and become useful in solving specific ranges of problems These methods pertain to the finite Laplace transformation to partial differential equations and to the Volterra integral equations and ordinary differential equations with variable coefficients This book can prove valuable for mathematicians students and professors of calculus and advanced mathematics

Operational Calculus in Two Variables and Its Applications V.A. Ditkin, A.P. Prudnikov, 2017-06-15 Concise treatment of fundamental theory explores two dimensional Laplace transform and basic definitions theorems applications of operational calculus in two variables Includes tables of formulae for various categories of functions 1962 edition

Complex Variable & Operational Calculus with Technical Applications Norman William McLachlan, 1942

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