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ORIGINAL RESEARCH **Open Access**

Solution Of Telegraph Equation By Double General Integral Transform

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Abstract

This paper presents a method for solving the Telegraph equation using the double general integral transform. The method involves transforming the equation into a second-order ordinary differential equation with variable coefficients, which is then solved using standard techniques. The results demonstrate the effectiveness of the method in solving the Telegraph equation.

Key words: Double general integral transform-New general integra transform-Telegraph equation.

AMS classification: 26A33;35A22

1 Introduction

Integral transform is a mathematical technique that allows us to transform a function from one domain to another, typically from the time or space domain to the frequency domain. It is widely used in many fields of science and engineering, including physics, mathematics, signal processing, and image processing.Integral transform was first introduced by the French mathematician Joseph Fourier in the early 19th century, who used it to solve heat conduction problems. Since then, many other mathematicians have contributed to the development and application of integral transforms, including:Laplace Transform, Fourier Transform, Hankel Transform, Mellin Transform, Radon Transform. Hossein Jafari [3] used a new general integral transform for solving integral equation.In March 2022 D.G.Kaklij [5] introduced double new general integral transform and its properties. D.P.Patil [2]

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[6] also used double general integral transform for obtaining the solution of boundary value problems and parabolic boundary value problems.

The Telegraph Equation is a partial differential equation that describes the propagation of electrical signals along a transmission line. It was first introduced by Oliver Heaviside in 1887 as a modification of the classical wave equation.In this paper we solve telegraph equation using double general integral transform,we directly convert telegraph equation into an algebraic equation instead of converting to ODE .Solving this algebraic equation and applying double inverse integral transform we obtain the exact solution. Solution of telegraph equation by double aboodh tranform by K.S.Aboodh,R.A.Farah,I.A.Almardy [1] on 2017.Further Emad-Sara and Emad-Falih [7] [8] transforms are used to handling telegraph equations.This method is illustrated by examples.

2 Preliminaries

Definition 2.1 ***Telegraph Equation***

The general form of telegraph equation is

$$\frac{\partial^2 u}{\partial t^2}+(\alpha+\beta)\frac{\partial u}{\partial t}+(\alpha\beta u)=c^2\frac{\partial^2 u}{\partial x^2} \tag{1}$$

Where $u(x,t)$ can be voltage or current through the wire at position x and time $t,\alpha=\frac{G}{C},\beta=\frac{R}{L}$ and $c^2=\frac{1}{LC}$,Where G is conductance of resistor ,R is resistance of resistor ,L is inductance of coil and C is capacitance of capacitor.

Definition 2.2 ***New General Integral Transform***

Let $f(t)$ be an integral function defined for $t\geq 0, p(s)\neq 0$ and $q(s)$ are positive real valued functions then the general integral transform $\mathscr{T}(s)$ of $f(t)$ is defined by

$$T[f(t)]=p(s)\int_0^\infty f(t)e^{-q(s)t}dt$$

Provided that the integral exits for some q(s).

Formulae for New general integral transform

Function $f(t)$	New integral transform $T(f(t)) = \mathscr{T}(s)$
1	$\frac{p(s)}{q(s)}$
t	$\frac{p(s)}{(q(s))^2}$
t^α	$\frac{\Gamma(\alpha+1)p(s)}{q(s)^{\alpha+1}}, \alpha > 0$
$\sin t$	$\frac{p(s)}{(q(s))^2+\alpha^2}$
$\sin \alpha t$	$\frac{\alpha p(s)}{(q(s))^2+\alpha^2}$
$\cos t$	$\frac{p(s)q(s)}{(q(s))^2+1}$
e^t	$\frac{p(s)}{q(s)-1}, q(s) > 1$
$f'(t)$	$q(s)\mathscr{T}(s) - p(s)f(0)$

Definition 2.3 ***Double general integral transform***

Let $f(x,t)$ be an integral function defined for the variables x and t in the quadrant $p_1(s) \neq 0, p_2(s) \neq 0$ and $q_1(s), q_2(s)$ are positive real functions.We define the double general integral transform $T_2\{f(x,t)\}$ by the formula

$$T_2\{f(x,t)\} = \mathscr{T}(s) = p_1(s)p_2(s)\int_0^\infty\int_0^\infty e^{-\{q_1(s)x+q_2(s)t\}} f(x,t)dxdt$$

provided that the integral exits for some $q_1(s), q_2(s)$.

Definition 2.4 ***Properties of Double general integral transform***

a) Linearity property:

$$T_2(s)\{af(x,t)+bg(x,t)\} = aT_2\{f(x,t)\} + bT_2\{g(x,t)\}$$

b)Shifting property:

$$If\ \ T_2\{x,t\} = \mathscr{T}(s) \tag{2}$$

then $T_2\left\{e^{-(ax+by)}f(x,t)\right\} = \mathscr{T}(s,a,b) = p_1(s)p_2(s)\int_0^\infty\int_0^\infty e^{-((q_1(s)+a)x+(q_2(s)+b)t)} f(x,t)dxdt$

c)Change of scale property:

$$T_2\left\{(x,t)\right\} = \mathscr{T}(s)$$

$$T_2\left\{f(ax,bt)\right\} = \frac{1}{ab}\mathscr{T}(s,a,b)$$

Definition 2.5 ***Double Integral Transform Formulas For Elementary Functions***

Function $f(x,t)$	Double General Integral Transform $T_2\left\{f(x,t)\right\}$
1	$\frac{p_1(s)p_2(s)}{q_1(s)q_2(s)}$
$exp(ax+bt)$	$\frac{p_1(s)p_2(s)}{(q_1(s)-a)(q_2(s)-b)}$
$exp(i(ax+bt))$	$\frac{p_1(s)p_2(s)}{(q_1(s)-ia)(q_2(s)-ib)}$
$cosh(ax+bt)$	$\frac{1}{2}\ [\frac{p_1(s)p_2(s)}{(q_1(s)-a)(q_2(s)-b)} + \frac{p_1(s)p_2(s)}{(q_1(s)+a)(q_2(s)+b)}]$
$sinh(ax+bt)$	$\frac{1}{2}[\frac{p_1(s)p_2(s)}{(q_1(s)-a)(q_2(s)-b)}$ - $\frac{p_1(s)p_2(s)}{(q_1(s)+a)(q_2(s)+b)}]$
$cos(ax+bt)$	$\frac{1}{2}\ [\frac{p_1(s)p_2(s)}{(q_1(s)-ia)(q_2(s)-ib)} + \frac{p_1(s)p_2(s)}{(q_1(s)+ia)(q_2(s)+ib)}]$
$sin(ax+bt)$	$\frac{1}{2}[\frac{p_1(s)p_2(s)}{(q_1(s)-ia)(q_2(s)-ib)}$ - $\frac{p_1(s)p_2(s)}{(q_1(s)+ia)(q_2(s)+ib)}]$
$(xy)^n, n>0$	$\frac{(\Gamma(n+1))^2 p_1(s)p_2(s)}{(q_1(s)q_2(s))^{n+1}}$
$x^m y^n, m>0, n>0$	$\frac{\Gamma(m+1)\Gamma(n+1)p_1(s)p_2(s)}{(q_1(s))^m+1)(q_2(s))^{n+1}}$

Theorem 2.6 Let (x,t) be a function of two variables.If the first ordered partial derivative $\frac{\partial f}{\partial x}$ and $\frac{\partial f}{\partial t}$ exits and $f(0,t)$ be given.$p_1(s), p_2(s), q_1(s)$ and $q_2(s)$ are positive real functions then

$$T_2\left\{\frac{\partial f}{\partial x}(x,t)\right\} = -p_1(s)T\left\{f(0,t)\right\} + q_1(s)T_2\left\{f(x,t)\right\}$$

Where ,$Tf(x,t)$is the new general integral transform of the $f(0,t)$.

Theorem 2.7 Let (x,t) be a function of two variables.If the first ordered partial derivative $\frac{\partial f}{\partial x}$ and $\frac{\partial f}{\partial t}$ exits and $f(x,0)$ be given.$p_1(s)$,$p_2(s)$,$q_1(s)$ and $q_2(s)$ are positive real function then

$$T_2\left\{\frac{\partial f}{\partial x}\right\} = -p_2(s)T\{f(x,0)\} + q_2(s)T_2\{f(x,t)\}$$

Where ,$Tf(x,0)$ is the new general integral transform of the $f(x,0)$

Theorem 2.8 Let (x,t) be a function of a two varaibles.If the first and second ordered partial derivative $\frac{\partial f}{\partial x}$,$\frac{\partial f}{\partial t}$,$\frac{\partial^2 f}{\partial x^2}$ and $\frac{\partial^2 f}{\partial t^2}$ are exists and $f(0,y)$,$f_x(0,y)$ be given. $p_1(s), p_2(s), q_1(s), q_2(s)$ are positive real functions then

$$T_2\left\{\frac{\partial^2}{\partial x^2}f(x,t)\right\} = -p_1(s)\left[T\{f_x(0,t)\} + q_1(s)T\{f(0,t)\}\right] + q_1(s)^2T_2\{f(x,t)\}$$

Where ,$Tf_x(0,t)$,$Tf(0,t)$ is the new general integral transform of the $f_x(0,t)$,$f(0,t)$ respectively

Proof: Applying transform on second order partial derivative with respect to x

$T_2\left\{\frac{\partial^2}{\partial x^2}f(x,t)\right\} = T_2\left\{\frac{\partial}{\partial x}f_x(x,t)\right\}$

$T_2\left\{\frac{\partial^2}{\partial x^2}f(x,t)\right\} = -p_1(s)T\{f_x(0,t)\} + q_1(s)T_2\{f_x(x,t)\}$

$T_2\left\{\frac{\partial^2}{\partial x^2}f(x,t)\right\} = -p_1(s)T\{f_x(0,t)\} + q_1(s)\left[-p_1(s)T\{f(0,t)\} + q_1(s)T_2\{f(x,t)\}\right]$

$T_2\left\{\frac{\partial^2}{\partial x^2}f(x,t)\right\} = -p_1(s)\left[T\{f_x(0,t)\} + q_1(s)T\{f(0,t)\}\right] + q_1(s)^2T_2\{f(x,t)\}$

Theorem 2.9 Let (x,t) be a function of two variables.If the first and second ordered partial derivative $\frac{\partial f}{\partial x}$,$\frac{\partial f}{\partial t}$,$\frac{\partial^2 f}{\partial x^2}$ and $\frac{\partial^2 f}{\partial t^2}$ are exists and $f(x,0)$,$f_x(0,t)$ be given. $p_1(s)$,$p_2(s)$,$q_1(s)$ and $q_2(s)$ are positive real function then

$$T_2\left\{\frac{\partial^2}{\partial t^2}f(x,t)\right\} = -p_2(s)\left[T\{f_t(x,0)\} + q_2(s)T\{f(x,0)\}\right] + q_2(s)^2T_2\{f(x,t)\}$$

Where ,$Tf_y(x,0)$,$Tf(x,0)$ is the new general integral transform of the $f_t(x,0)$b,$f(x,0)$ respectively.

Proof: Applying transform on second order partial derivative with respect to t

$T_2\left\{\frac{\partial^2}{\partial t^2}f(x,t)\right\} = T_2\left\{\frac{\partial}{\partial t}f_t(x,t)\right\}$

$T_2\left\{\frac{\partial^2}{\partial t^2}f(x,t)\right\} = -p_2(s)T\{f_t(x,0)\} + q_2(s)T_2\{f_t(x,t)\}$

$$T_2\left\{\frac{\partial^2}{\partial t^2}f(x,t)\right\}=-p_2(s)T\left\{f_t(x,0)\right\}+q_2(s)\left[-p_2(s)T\left\{f(x,0)\right\}+q_2(s)T_2\left\{f(x,t)\right\}\right]$$

$$T_2\left\{\frac{\partial^2}{\partial t^2}f(x,t)\right\}=-p_2(s)\left[T\left\{f_t(x,0)\right\}+q_2(s)T\left\{f(x,0)\right\}\right]+q_2(s)^2T_2\left\{f(x,t)\right\}$$

3 Application

Example 3.1 Consider the telegraph equation

$$U_{xx}=U_{tt}+U_t+U \tag{3}$$

with boundary condition

$$U(0,t)=e^{-t},U_x(0,t)=e^{-t} \tag{4}$$

with initial condition

$$U(x,0)=e^{x},U_t(x,0)=-e^{x} \tag{5}$$

Solution: Let $U_{xx}=U_{tt}+U_t+U$

Applying double general integral transform of (3)

$T_2(U_{xx})=T_2(U_{tt})+T_2(U_t)+T_2(U)$

$T_2\left\{\frac{\partial}{\partial x}U_x(x,t)\right\}=-p_1(s)\left[T\left\{U_x(0,t)\right\}+q_1(s)T\left\{U(0,t)\right\}\right]+q_1(s)^2T_2\left\{U(x,t)\right\}$

$T_2\left\{\frac{\partial}{\partial t}U_t(x,t)\right\}=-p_2(s)\left[T\left\{U_t(x,0)\right\}+q_2(s)T\left\{U(x,0)\right\}\right]+q_2(s)^2T_2\left\{U(x,t)\right\}$

$T_2\left\{\frac{\partial U}{\partial t}(x,t)\right\}=-p_2(s)T\left\{U(x,0)\right\}+q_2(s)T_2\left\{U(x,t)\right\}$

$T_2(U)=T_2U(x,t)$

$$-p_1(s)\left[T_x(0,v)+q_1(s)T(0,V)\right]+q_1(s)^2T_2(u,v)$$

$$=-p_2(s)\left[T_t(u,0)+q_2(s)T(U,0)\right]+q_2(s)^2T_2(u,v)-p_2(s)T(u,0)+q_2(s)T_2(u,v)+T_2(u,v) \tag{6}$$

And Apply single general integral transform of conditions of (4),(5) then we have

$$T(0,v)=\frac{p_2(s)}{q_2(s)+1}\quad,\quad\frac{\partial T}{\partial x}(0,v)=\frac{p_2(s)}{q_2(s)+1} \tag{7}$$

$$T(u,0)=\frac{p_1(s)}{q_1(s)-1}\quad,\quad\frac{\partial T}{\partial t}(u,0)=-\frac{p_1(s)}{q_1(s)-1} \tag{8}$$

Substituting (7),(8) in (6) we obtain

$-p_1(s)\left[\frac{p_2(s)}{q_2(s)+1}+\frac{q_1(s)p_2(s)}{q_2(s)+1}\right]+q_1(s)^2T_2(u,v)=-p_2(s)\left[-\frac{p_1(s)}{q_1(s)-1}+\frac{q_2(s)p_1(s)}{q_1(s)-1}\right]$

$+q_2(s)^2T_2(u,v)-\frac{p_1(s)p_2(s)}{q_1(s)-1}+q_2(s)T_2(u,v)+T_2(u,v)$

$$T_2(s)[q_1(s)^2-q_2(s)^2-q_2(s)-1]=\frac{p_1(s)p_2(s)}{q_2(s)+1}+\frac{p_1(s)p_2(s)q_1(s)}{q_2(s)+1}+\frac{p_1(s)p_2(s)}{q_1(s)-1}$$

$$-\frac{p_1(s)p_2(s)q_2(s)}{q_1(s)-1}-\frac{p_1(s)p_2(s)}{q_1(s)-1}$$

$$T_2(u,v)\left[q_(s)^2-q_2(s)^2-q_2(s)-1\right]=\frac{p_1(s)p_2(s)\left[q_1(s)^2-q_2(s)^2-q_2(s)-1\right]}{(q_2(s)+1)(q_1(s)-1)}$$

$$T_2(u,v)=\frac{p_1(s)p_2(s)}{(q_2(s)+1)(q_1(s)-1)}$$

$$T_2(u,v)=\frac{p_1(s)}{q_1(s)-1}\,\frac{p_2(s)}{q_2(s)+1} \tag{9}$$

The function U(x,t) could be obtained using double inverse of integral transform to get the solution of equation(9) in the form

$$U(x,t)=e^xe^{-t}=e^{x-t}$$

Example 3.2 Consider the telegraph equation

$$U_{xx}=U_{tt}+4U_t+5U \tag{10}$$

With boundary condition

$$U(0,t)=e^{-2t},U_x(0,t)=e^{-2t} \tag{11}$$

With initial condition

$$U(x,0)=e^x,U_t(x,0)=-2e^x \tag{12}$$

solution: Let $U_{xx}=U_{tt}+4U_t+5U$

Applying double general integral transform of (10)

$T_2(U_{xx})=T_2(U_{tt})+T_2(4U_t)+T_2(5U)$

$$T_2\left\{\frac{\partial}{\partial x}U_x(x,t)\right\}=-p_1(s)\left[T\left\{U_x(0,t)\right\}+q_1(s)T\left\{U(0,t)\right\}\right]+q_1(s)^2T_2\left\{U(x,t)\right\}$$

$$T_2\left\{\frac{\partial}{\partial x}U_t(x,t)\right\}=-p_2(s)\left[T\left\{U_x(x,0)\right\}+q_1(s)T\left\{U(x,0)\right\}\right]+q_2(s)^2T_2\left\{U(x,t)\right\}$$

$$T_2\left\{U_t(x,t)\right\}=-p_2(s)T\left\{U(x,0)\right\}+q_2(s)T_2\left\{U(x,t)\right\}$$

$$T_2(U)=T_2U(x,t)$$

$$-p_1(s)\left[T_x(0,v)+q_1(s)T(0,v)\right]+q_1(s)^2T_2(u,v)=-p_2(s)\left[T_t(u,0)+q_2(s)T(u,0)\right]+ q_2(s)^2T_2(u,v)+4\left[-p_2(s)T(u,0)+q_2(s)T_2(u,v)\right]+5T_2(u,v) \tag{13}$$

And Apply single general integral transform of conditions of (11),(12) then we have

$$T(0,v)=\frac{p_2(s)}{q-2(s)+2} \quad , \quad \frac{\partial T}{\partial x}(0,v)=\frac{p_2(s)}{q_2(s)+2} \tag{14}$$

$$T(u,0)=\frac{p_1(s)}{q_1(s)-1} \quad , \quad \frac{\partial T}{\partial t}(u,0)=\frac{-2p_1(s)}{q_1(s)-1} \tag{15}$$

Substituting (14) ,(15) in (13)we obtain

$$-p_1(s)\left[\frac{p_2(s)}{q_2(s+2)}+\frac{q_1(s)p_2(s)}{q_2(s)+2}\right]+q_1(s)^2T(u,v)=-p_2(s)\left[\frac{-2p_1(s)}{q_1(s)-1}+\frac{q_2(s)p_1(s)}{q_1(s)-1}\right]$$
$$+q_2(s)^2T(u,v)+\left[\frac{-4p_2(s)p_1(s)}{q_1(s)}+4q_2(s)T(u,v)\right]+5T(u,v)$$

$$T(u,v)\left[q_1(s)^2-q_2(s)^2-4q_2(s)-5\right]=\frac{p_1(s)p_2(s)\left[q_1(s)^2-q_2(s)^2-4q_2(s)-5\right]}{(q_2(s)+2)(q_1(s)-1)}$$

$$T(u,v)=\frac{p_1(s)p_2(s)}{(q_2(s)+2)(q_1(s)-1)}$$

$$T(u,v)=\frac{p_1(s)}{(q_1(s)-1}\,\frac{p_2(s)}{q_2(s)+2} \tag{16}$$

The function U(x,t) could be obtained using double inverse of integral transform to get the solution of equation(16) in the form

$$U(x,t)=e^xe^{-2t}=e^{x-2t}$$

Example 3.3 Consider the telegraph equation

$$U_{tt}+aU_t+bU=C^2U_{xx} \tag{17}$$

With boundary condition

$$U(0,t)=f_1(t) \quad , \quad U_x(0,t)=g_1(t) \tag{18}$$

With initial condition

$$U(x,0)=f_2(t) \quad , \quad U_t(x,0)=g_2(x) \tag{19}$$

Solution: Let$U_{tt}+aU_t+bU=C^2U_{xx}$

$$c^2\left(\frac{\partial}{\partial x}U_x(x,t)\right)=\left(\frac{\partial}{\partial t}U_t(x,t)\right)+\left(a\frac{\partial}{\partial t}U(x,t)\right)+b\left(U(x,t)\right)$$

$$\frac{\partial}{\partial x}U_x(x,t)=-p_1(s)\left[U_x(0,t)+q_1(s)U(0,t)\right]+q_1(s)^2U(x,t)$$

$$\frac{\partial}{\partial t}U_t(x,t)=-p_2(s)\left[U_t(x,0)+q_2(s)U(x,0)\right]+q_2(s)^2U(x,t)$$

$$\frac{\partial}{\partial t}U(x,t)=-p_2(s)\left[U(x,0)\right]+q_2(s)\left[U(x,t)\right]$$

$$U(x,t)=U(x,t)$$

$$-p_2(s)\left[\tfrac{\partial T}{\partial t}(u,0)+q_2(s)T(u,0)\right] + q_2(s)^2T(u,v) + a\left[-p_2(s)T(u,0)+q_2(s)T(u,v)\right] + b\left[T(u,v)\right]$$
$$=c^2\left[\left\{-p_1(s)\frac{\partial T}{\partial x}+q_1(s)T(0,v)\right\}+q_1(s)^2T(u,v)\right] \tag{20}$$

$$\mathit{And} \quad T(0,v)=F_1(v) \quad , \quad \frac{\partial T}{\partial x}(0,v)=G_1(v) \tag{21}$$

$$T(u,0)=F_2(u) \quad , \quad \frac{\partial T}{\partial t}(u,0)=G_2(u) \tag{22}$$

Substituting (21)and(22) in (20) we obtain

$$-p_2(s)\left[G_2(u)+q_2(s)F_2(u)\right]+q_2(s)^2T(u,v)+a\left[-p_2(s)F_2(u)+q_2(s)T(u,v)\right]+bT(u,v)$$

$$=c^2\left[\{-p_1(s)G_1(v)+q_1(s)F_1(v)\}+q_1(s)^2T(u,v)\right] \tag{23}$$

$$-p_2(s)G_2(u)-p_2(s)F_2(u)+q_2(s)^2T(u,v)-ap_2(s)F_2(u)+aq_2(s)T(u,v)+bT(u,v)$$
$$=-c^2p_1(s)G_1(v)+c^2q_1(s)F_1(v)+c^2q_1(s)^2T(u,v)+q_2(s)^2T(u,v)+aq_2(s)T(u,v)$$
$$+bT(u,v)-c^2q_1(s)^2T(u,v)$$
$$T(u,v)\left[q_2(s)^2+aq_2(s)+b-c^2q_1(s)^2\right]=p_2(s)G_2(u)+p_2(s)q_2(s)F_2(u)+ap_2(s)F_2(u)$$
$$-c^2p_1(s)G_1(v)+c^2q_1(s)F_1(v)$$

$$T(u,v)=\frac{\left[p_2(s)G_2(u)+p_2(s)q_2(s)F_2(u)+ap_2(s)F_2(u)-c^2p_1(s)G_1(v)+c^2q_1(s)F_1(v)\right]}{\left[q_2(s)^2+aq_2(s)+b-c^2q_1(s)^2\right]}$$

$$T(u,v)=H(u,v) \tag{24}$$

Take double inverse general integral transform to obtain the solution of general telegraph (17)in the form

$$U(x,t)=T_2^{-1}[H(u,v)]=T(x,t) \tag{25}$$

Assumed that the double inverse general integral transform is exists.

4 Conclusion

In this paper we succesfully obtain A double general transform and then applied it to the telegraph equation to find the exact solution of it.The result was impressive where this equation was solved simply and easily.It may be concluded that double general integral transform is very powerful and effective in finding the analytical solution of a partial differential equations.

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