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Laplace Transforms to Kekre's functions

H. B. Kekre[1], V. R. Lakshmi Gorty[2]

Senior Professor, Department of Computer Science, SVKM's NMIMS MPSTME, Mumbai, India[1]

Associate Professor, Department of Computer Science, SVKM's NMIMS MPSTME, Mumbai, India[2]

Abstract: In this paper, the Kekre's function is represented in mathematical concept. The Laplace transforms is applied to Kekre's function and the results are obtained. The graphical representation is shown by MATLAB also to show the Kekre's function. A generalized representation of Kekre's function is shown in this paper. To all the assigned order *N,* of the Kekre's functions, the solutions are displayed for each example. Linearity property using Laplace transforms when applied to Kekre's function, is proved in the form of a theorem. For any positive arbitrary value, the transform of Kekre function is obtained and also shown how Kekre's function is related to inverse Laplace transforms. At the end of examples, the generalized representation of the Laplace transforms of Kekre's function is formulated.

Keywords*:* Kekre's function, Laplace transforms, generalized representation, linearity property

I. INTRODUCTION

Kekre function is defined as

$$K_a(t) = -(N-a)\left[u(t-(a-1)) - u(t-a)\right] + u(t-a) \tag{1}$$

for any order, $a = 0,1,2,3,...N$ and $a < N$.

Here N is the order of the Kekre's function. Transform methods are typically used in many image processing applications such as compression, filtering, enhancement, feature extraction, image texture analysis etc. Using transform domain techniques, it is possible to embed a secret message in different frequency bands of the cover image. There are a number of linear transformations that prove useful in digital image processing. Most commonly used transforms are Discrete Cosine Transform (DCT), Discrete Sine Transform (DST), Walsh, Haar [15] etc. This paper proposes transforms applied to Kekre's function [15] and can be used for various image processing applications. CBIR technology is implemented in a host of different applications which include art galleries, museums, archaeology [1],[2], architecture/engineering design [3], geographic information systems [5], weather forecast [4], medical imaging [4], trademark databases [6], criminal records [7], World Wide Web like photo sharing and video streaming sites[8]. Some of recent works on speaker identification depend on classical features including cepstrum with many variants [9], sub-band processing technique [10], Gaussian mixture models (GMM) [11], linear prediction coding [12], wavelet transform [13] and neural networks [14]. A lot of work in different applications to engineering fields has been done. But still there is lack of understanding of the mathematical interpretation using Kekre's function is been observed. The author in the present study, proposes solution to some problems using Kekre's function which will help further in application problems. In this paper, Kekre's function is used to solve few problems using Laplace Transforms.

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Volume 2, Issue 10, October 2013

II. PRELIMINARY STUDY

Here the order of the Kekre's function is '4'. Then the Kekre's function can be represented as:

$$K_0 = u(t-0)$$

$$K_1 = -3\big(u(t-0) - u(t-1)\big) + u(t-1)$$

$$K_2 = -2\big(u(t-1) - u(t-2)\big) + u(t-2)$$

$$K_3 = -1\big(u(t-2) - u(t-3)\big) + u(t-3)$$

Using MATLAB code, the Kekre function is represented as

```
t=[0.1: 0.1:4]
K0=heaviside(t)
Plot(t,K1)
K1=-3.*(heaviside(t-0)-heaviside(t-1))+heaviside(t-1)
plot(t,K2,'*')
K2=-2.*(heaviside(t-1)-heaviside(t-2))+heaviside(t-2)
plot(t,K3,'g+')
K3=-1.*(heaviside(t-2)-heaviside(t-3))+heaviside(t-3)
plot(t,K4,'r+').
```

When the order of Kekre's function is '5'.
Then the Kekre's function can be represented as:

$$K_0 = u(t-0)$$

$$K_1 = -4\big(u(t-0) - u(t-1)\big) + u(t-1)$$

$$K_2 = -3\big(u(t-1) - u(t-2)\big) + u(t-2)$$

$$K_3 = -2\big(u(t-2) - u(t-3)\big) + u(t-3)$$

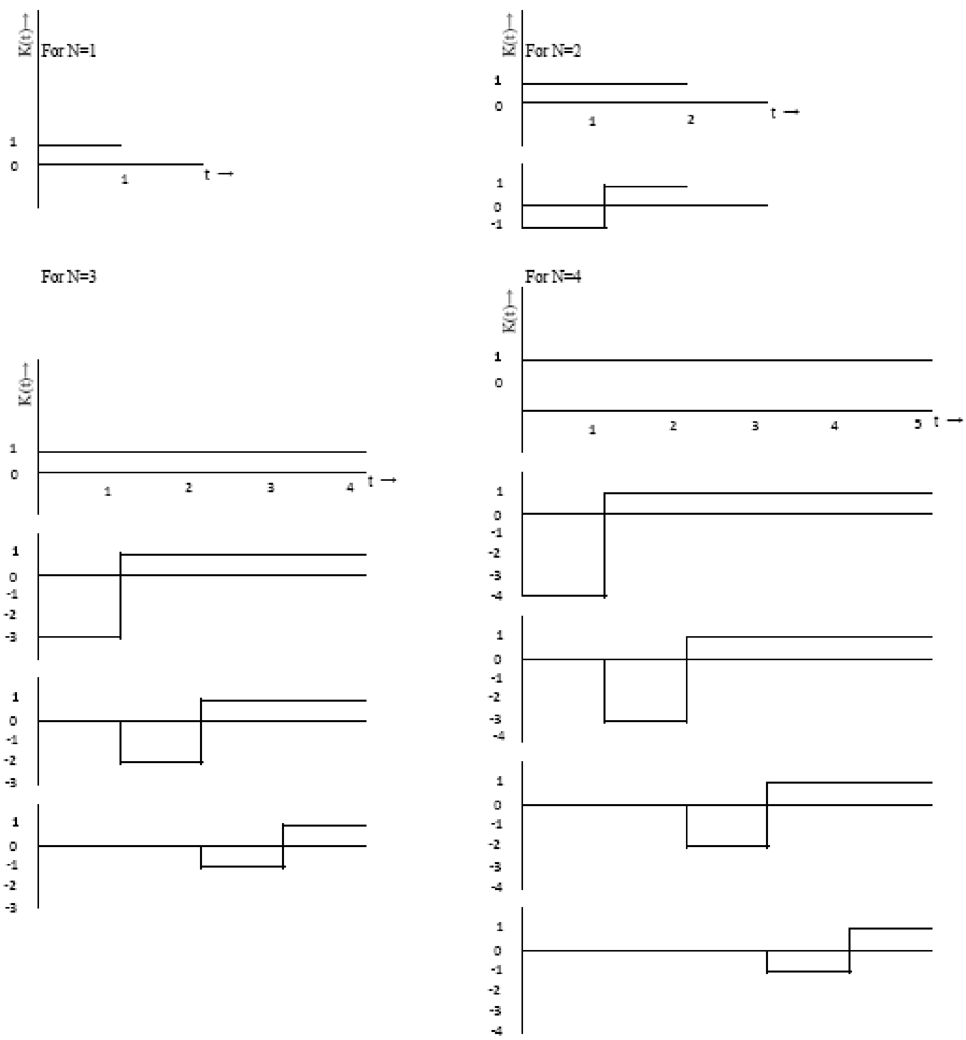
$$K_4 = -1\big(u(t-3) - u(t-4)\big) + u(t-4)$$

Using MATLAB code, the Kekre function is represented as

```
t=[0.1: 0.1:5]
K0=heaviside(t)
plot(t,K1,'*')
hold on
K1=-4.*(heaviside(t-0)-heaviside(t-1))+heaviside(t-1)
plot(t,K2,'O')
hold on
K2=-3.*(heaviside(t-1)-heaviside(t-2))+heaviside(t-2)
plot(t,K3,'g-')
hold on
K3=-2.*(heaviside(t-2)-heaviside(t-3))+heaviside(t-3)
plot(t,K4,'b-')
hold on
```

```
K4=-1.*(heaviside(t-3)-heaviside(t-4))+heaviside(t-4)
plot(t,K5,'r-')
```

Graphical representation of Kekre's function of order 1,2,3,4 is given below:



Similarly for any order, Kekre's function can be represented as
For $a = 0,1,2,3,...N$ and $a < N$.

$$K_0(t) = u(t) \tag{2}$$

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Volume 2, Issue 10, October 2013

always for any N; with reference to the function formula given in [15], the generalized Kekre's function is given by $K_a(t) = -(N-a)\left[u(t-(a-1)) - u(t-a)\right] + u(t-a)$

Linearity Property

Theorem 1: The linear operation with Kekre's function over functions $f(x)$ and $g(x)$ and for any constants a and b,

$$L\left[\mathcal{K}(N;x)\{a\,f(x)+b\,g(x)\}\right] = a\,L\left[\mathcal{K}(N;x)\,f(x)\right] + b\,L\left[\mathcal{K}(N;x)\,g(x)\right]. \quad (3)$$

Proof: By the definition,

$$L\left[\mathcal{K}(N;x)\,f(x)\right] = \int_0^\infty e^{-sx} K(N;x)\,f(x)\,dx$$

$$L\left[\mathcal{K}(N;x)\,g(x)\right] = \int_0^\infty e^{-sx} K(N;x)\,g(x)\,dx$$

$$L\left[\mathcal{K}(N;x)\{af(x)+bg(x)\}\right] = \int_0^\infty e^{-st} K(N;x)\{af(x)+bg(x)\}\,dx$$

$$= a\int_0^\infty e^{-st} K(N;x)\,f(x)\,dx + b\int_0^\infty e^{-st} K(N;x)\,g(x)\,dx$$

$$= a\,L\left[\mathcal{K}(N;x)\,f(x)\right] + bL\left[\mathcal{K}(N;x)\,g(x)\right].$$

Theorem 2: If $F(s)$ is the transform of $f(t)$, then $e^{-as}F(s); a>0$, 'a' is any positive arbitrary value, the transform of Kekre function $K_a(N;t) = -(N-a)\left[u(t-(a-1)) - u(t-a)\right] + u(t-a)$, $L\left(K_a(N;t)\right) = (N-a)\dfrac{e^{s}}{s} - \dfrac{e^{-sa}}{s}$.

(4)

Thus

$$L^{-1}\left[\frac{e^{s}(N-a) - e^{-as}}{s}\right] = K_a(N;t). \quad (5)$$

Proof: From the definition,

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Volume 2, Issue 10, October 2013

$$L\left(K_a\left(N;t\right)\right)=\int_0^\infty e^{-st}K_a\left(N;t\right)dt=\int_0^\infty e^{-st}\left[-\left(N-a\right)\left\{u\left(t-\left(a-1\right)\right)-u\left(t-a\right)\right\}+u\left(t-a\right)\right]dt$$

$$=\int_0^\infty e^{-st}\left[-\left(N-a\right)u\left(t-\left(a-1\right)\right)+\left\{\left(N-a\right)+1\right\}u\left(t-a\right)\right]dt$$

$$=-\int_0^{a-1} e^{-st}\left(N-a\right)0dt-\int_{a-1}^\infty e^{-st}\left(N-a\right).1dt+\int_0^a e^{-st}\left(N-a+1\right)0dt+\int_a^\infty e^{-st}\left(N-a+1\right).1dt$$

$$=\left[-\frac{e^{-st}}{s}\left(N-a\right)\right]_{a-1}^\infty+\left[\frac{e^{-st}}{s}\left(N-a+1\right)\right]_a^\infty$$

$$=\frac{e^{-s(a-1)}}{s}\left(N-a\right)-\frac{e^{-sa}}{s}\left(N-a+1\right)$$

$$=\left(N-a\right)\frac{e^{s}}{s}-\frac{e^{-sa}}{s}.$$

This relation holds true for value of N, for all values $a=1,2,3,...N$ and $a<N$.

This follows directly from the derived that,

$$L^{-1}\left[\frac{e^{s}\left(N-a\right)-e^{-as}}{s}\right]=K_a\left(N;t\right).$$

III. CALCULATIONS

For a function $t\,K_a\left(N;t\right)$ the Laplace transforms is applied and calculated for $N=5;a=0,1,2,3,4$. On applying Laplace transforms over Kekre's function from (1), the following results are obtained.

$$L\{t\,K_0(5;t)\}=\frac{1}{s^2}.$$

$$L\{t\,K_1(5;t)\}=\frac{-4+5e^{-s}s+5e^{-s}}{s^2}.$$

$$L\{t\,K_2(5;t)\}=\frac{-3se^{-s}-3e^{-s}+8se^{-2s}+4e^{-2s}}{s^2}.$$

$$L\{t\,K_3(5;t)\}=\frac{-4se^{-2s}-2e^{-2s}+9se^{-3s}+3e^{-3s}}{s^2}.$$

$$L\{t\,K_4(5;t)\}=\frac{-3se^{-3s}-e^{-3s}+8se^{-4s}+2e^{-4s}}{s^2}.$$

Thus the generalized form of the transforms can be written as

$$L\{t\,K_a(N;t)\}=\frac{\begin{bmatrix}-\{(a-1)(N-a)s+(N-a)\}e^{-(a-1)(s)}\\+\{a(N+1-a)s+(N+1-a)\}e^{-as}\end{bmatrix}}{s^2} \quad (6)$$

Consider $t^2\,K_a(N;t)$ for $N=4; a=0,1,2,3.$ On applying Laplace transforms over Kekre's function from (1),), the following results are obtained.

$$L\{t^2\,K_0(4;t)\}=\frac{2}{s^3}.$$

$$L\{t^2\,K_1(4;t)\}=\frac{-6+(4s^2+8s+8)e^{-s}}{s^3}.$$

$$L\{t^2\,K_2(4;t)\}=\frac{-e^{-s}(2s^2+4s+4)+e^{-2s}(12s^2+12s+6)}{s^3}.$$

$$L\{t^2\,K_3(4;t)\}=\frac{-e^{-2s}(4s^2+4s+2)+e^{-3s}(18s^2+12s+4)}{s^3}.$$

Thus the generalized form of the transforms can be written as

$$L\left\{t^2 K_a(N;t)\right\}=\frac{\begin{bmatrix}-\left\{(a-1)^2(N-a)s^2+2(a-1)(N-a)s+2(N-a)\right\}e^{-(a-1)(s)}\\+\left\{a^2(N+1-a)s^2+2a(N+1-a)s+2(N+1-a)\right\}e^{-as}\end{bmatrix}}{s^2}. \tag{7}$$

Applying Laplace transforms over Kekre's function (1), in the form of $L\left\{e^{-bt}K_a(N;t)\right\}$, for $N=4; a=0,1,2,3,$ the following results are obtained.

$$L\left\{e^{-bt}K_0(4;t)\right\}=\frac{1}{s+b}.$$

$$L\left\{e^{-bt}K_1(4;t)\right\}=\frac{-3+4e^{-(s+b)}}{s+b}.$$

$$L\left\{e^{-bt}K_2(4;t)\right\}=\frac{-2e^{-(s+b)}+3e^{-2(s+b)}}{s+b}.$$

$$L\left\{e^{-bt}K_3(4;t)\right\}=\frac{-e^{-2(s+b)}+2e^{-3(s+b)}}{s+b}.$$

$$L\left\{e^{-bt}K_a(N;t)\right\}=\frac{-(N-a)e^{-(a-2)(s+b)}+(N+1-a)e^{-(a-1)(s+b)}}{s+b}.$$

Thus the generalized form of the transforms can be written as

$$L\left\{e^{-bt}K_a(N;t)\right\}=\frac{-(N-a)e^{-(a-2)(s+b)}+(N+1-a)e^{-(a-1)(s+b)}}{s+b}. \tag{8}$$

To find Laplace of $L\left\{\sin bt\, K_a(N;t)\right\}$ for $N=4; a=0,1,2,3,$ by applying Laplace transforms over Kekre's function (1),

$$L\left\{\sin bt\, K_0(4;t)\right\}=\frac{b}{s^2+b^2}.$$

$$L\left\{\sin bt\, K_1(4;t)\right\}=\frac{-3b+4e^{-s}\cos b+4se^{-s}\sin b}{s^2+b^2}.$$

$$L\left\{\sin bt\, K_2(4;t)\right\}=\frac{-2be^{-s}\cos b-2se^{-s}\sin b+3be^{-2s}\cos 2b+3se^{-2s}\sin 2b}{s^2+b^2}.$$

$$L\left\{\sin bt\, K_3(4;t)\right\}=\frac{-be^{-2s}\cos 2b-se^{-2s}\sin 2b+2be^{-3s}\cos 3b+2se^{-3s}\sin 3b}{s^2+b^2}.$$

Thus the generalized form of the transforms can be written as

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(An ISO 3297: 2007 Certified Organization)

Volume 2, Issue 10, October 2013

$$L\{\sin bt\ K_a(N;t)\} = \frac{\begin{bmatrix} -(N-a)\left[b\cos\{(a-1)b\} + s\sin\{(a-1)b\}\right]e^{-(a-1)s} \\ +(N+1-a)\left[b\cos\{ab\} + s\sin\{ab\}\right]e^{-as} \end{bmatrix}}{s^2+b^2}. \quad (9)$$

Similarly for Laplace of $L\{\cos bt\, K_a(N;t)\}$ for $N=4; a=0,1,2,3.$ Thus applying Laplace transforms over Kekre's function (1),

$$L\{\cos bt\, K_0(4;t)\} = \frac{s}{s^2+b^2}.$$

$$L\{\cos bt\, K_1(4;t)\} = \frac{-3s+4e^{-s}s\cos b - 4be^{-s}\sin b}{s^2+b^2}.$$

$$L\{\cos bt\, K_2(4;t)\} = \frac{-2se^{-s}\cos b + 2be^{-s}\sin b + 3se^{-2s}\cos 2b - 3be^{-2s}\sin 2b}{s^2+b^2}.$$

$$L\{\cos bt\, K_3(4;t)\} = \frac{-se^{-2s}\cos 2b - be^{-2s}\sin 2b + 2se^{-3s}\cos 3b - 2be^{-3s}\sin 3b}{s^2+b^2}.$$

Thus the generalized form of the transforms can be written as

$$L\{\cos bt\ K_a(N;t)\} = \frac{\begin{bmatrix} -(N-a)\left[s\cos\{(a-1)b\} + b\sin\{(a-1)b\}\right]e^{-(a-1)s} \\ +(N+1-a)\left[s\cos\{ab\} - b\sin\{ab\}\right]e^{-as} \end{bmatrix}}{s^2+b^2}. \quad (10)$$

When Laplace of $L\{\sqrt{bt}\, K_a(N;t)\}$, is to be calculated for $N=5; a=0,1,2,3,4$ applying Laplace transforms over Kekre's function (1), the following results are obtained.

$$L\{\sqrt{bt}\, K_0(5;t)\} = \frac{1}{2}\frac{\sqrt{b\pi}}{s^{3/2}}.$$

$$L\{\sqrt{bt}\, K_1(5;t)\} = \frac{1}{2}\frac{\sqrt{b}\left\{-4\sqrt{\pi} + 10\sqrt{s}\ e^{-s} + 5\sqrt{\pi}\ erfc\sqrt{s}\right\}}{s^{3/2}}.$$

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Volume 2, Issue 10, October 2013

$$L\left\{\sqrt{bt}\,K_2(5;t)\right\}=\frac{1}{2}\frac{\sqrt{b}\left\{-6\sqrt{s}\;e^{-s}-3\sqrt{\pi}\,erfc\sqrt{s}+8\sqrt{2s}\;e^{-2s}+4\sqrt{\pi}\;erfc\sqrt{2s}\right\}}{s^{3/2}}.$$

$$L\left\{\sqrt{bt}\,K_3(5;t)\right\}=\frac{1}{2}\frac{\sqrt{b}\left\{-4\sqrt{2s}\;e^{-2s}-2\sqrt{\pi}\,erfc\sqrt{2s}+6\sqrt{3s}\;e^{-3s}+3\sqrt{\pi}\;erfc\sqrt{3s}\right\}}{s^{3/2}}.$$

$$L\left\{\sqrt{bt}\,K_4(5;t)\right\}=\frac{1}{2}\frac{\sqrt{b}\left\{-2\sqrt{3s}\;e^{-3s}-\sqrt{\pi}\,erfc\sqrt{3s}+8\sqrt{s}\;e^{-4s}+2\sqrt{\pi}\;erfc\left(\sqrt{4s}\right)\right\}}{s^{3/2}}.$$

Thus the generalized form of the transforms can be written as

$$L\left\{\sqrt{bt}\;K_a(N;t)\right\}=\frac{1}{2}\frac{\sqrt{b}\begin{bmatrix}-(N-a)(a-2)e^{-(a-2)s}\sqrt{(a-2)s}-(N-a)\sqrt{\pi}\,erfc\sqrt{(a-2)s}\\+(N+1-a)(a-1)e^{-(a-1)s}+(N+1-a)\sqrt{\pi}\,erfc\left(\sqrt{(a-1)s}\right)\end{bmatrix}}{s^{3/2}}. \quad (11)$$

Considering $L\left\{e^{iwt}K_a(N;t)\right\}$ for $N=5; a=0,1,2,3,4$ for the output. Applying Laplace transforms over Kekre's function (1), the results are displayed.

$$L\left\{e^{iwt}\;K_0(5;t)\right\}=\frac{1}{s-iw}.$$

$$L\left\{e^{iwt}\;K_1(5;t)\right\}=\frac{-4+5e^{-(s-iw)}}{s-iw}.$$

$$L\left\{e^{iwt}\;K_2(5;t)\right\}=\frac{-3e^{-(s-iw)}+4e^{-2(s-iw)}}{s-iw}.$$

$$L\left\{e^{iwt}\;K_3(5;t)\right\}=\frac{-2e^{-2(s-iw)}+3e^{-3(s-iw)}}{s-iw}.$$

$$L\left\{e^{iwt}\;K_4(5;t)\right\}=\frac{-e^{-3(s-iw)}+2e^{-4(s-iw)}}{s-iw}.$$

Thus the generalized form of the transforms can be written as

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Volume 2, Issue 10, October 2013

$$L\left\{e^{iwt}\,K_a\left(N;t\right)\right\}=\frac{-\left(N-a\right)e^{-(a-1)(s-iw)}+\left(N+1-a\right)e^{-a(s-iw)}}{s-iw}. \quad (12)$$

For the Laplace of $L\left\{\cosh bt\;K_a\left(N;t\right)\right\}$, on applying Laplace transforms over Kekre's function (1), for $N=5;a=0,1,2,3,4,$

$$L\left\{\cosh bt\;K_0\left(5;t\right)\right\}=\frac{s}{s^2-b^2},$$

$$L\left\{\cosh bt\;K_1\left(5;t\right)\right\}=\frac{-4s+5se^{-s}\cosh b+5be^{-s}\sinh b}{s^2-b^2},$$

$$L\left\{\cosh bt\;K_2\left(5;t\right)\right\}=\frac{-3se^{-s}\cosh b-3be^{-s}\sinh b+4se^{-2s}\cosh 2b+4be^{-2s}\sinh 2b}{s^2-b^2},$$

$$L\left\{\cosh bt\;K_3\left(5;t\right)\right\}=\frac{-2se^{-2s}\cosh b-2be^{-2s}\sinh b+3se^{-3s}\cosh 2b+3be^{-3s}\sinh 2b}{s^2-b^2},$$

$$L\left\{\cosh bt\;K_4\left(5;t\right)\right\}=\frac{-se^{-3s}\cosh 3b-be^{-3s}\sin 3b+2se^{-4s}\cosh 4b+2be^{-4s}\sinh 4b}{s^2-b^2},$$

the following results are obtained.

Thus the generalized form of the transforms can be written as

$$L\left\{\cosh bt\;K_a\left(N;t\right)\right\}=\frac{\begin{bmatrix}e^{-(a-1)s}\left(N-a\right)\left(s\cosh\left(a-1\right)b-b\sin\left(a-1\right)b\right)\\+e^{-as}\left(N+1-a\right)\left(\left(a-1\right)s\cosh ab+\left(a-1\right)b\sinh ab\right)\end{bmatrix}}{s^2-b^2}. \quad (13)$$

For finding Laplace of $L\left\{\sinh bt\;K_a\left(N;t\right)\right\}$ for $N=5;a=0,1,2,3,4$ and applying Laplace transforms over Kekre's function (1), the following results are displayed.

$$L\left\{\sinh bt\;K_0\left(5;t\right)\right\}=\frac{b}{s^2-b^2}.$$

$$L\left\{\sinh bt\;K_1\left(5;t\right)\right\}=\frac{-4b+5be^{-s}\cosh b+5se^{-s}\sinh b}{s^2-b^2}.$$

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Volume 2, Issue 10, October 2013

$$L\left\{\sinh bt\ K_2\left(5;t\right)\right\} = \frac{-3be^{-s}\cosh b - 3se^{-s}\sinh b + 4be^{-2s}\cosh 2b + 4se^{-2s}\sinh 2b}{s^2 - b^2}.$$

$$L\left\{\sinh bt\ K_3\left(5;t\right)\right\} = \frac{-2be^{-2s}\cosh b - 2se^{-2s}\sinh b + 3be^{-3s}\cosh 2b + 3se^{-3s}\sinh 2b}{s^2 - b^2}.$$

$$L\left\{\sinh bt\ K_4\left(5;t\right)\right\} = \frac{-be^{-3s}\cosh 3b - se^{-3s}\sin 3b + 2be^{-4s}\cosh 4b + 2se^{-4s}\sinh 4b}{s^2 - b^2}.$$

Thus the generalized form of the transforms can be written as

$$L\left\{\sinh bt\ K_a\left(N;t\right)\right\} = \frac{\begin{bmatrix} e^{-(a-1)s}\left(N-a\right)\left(b\cosh\left(a-1\right)b - s\sin\left(a-1\right)b\right) \\ +e^{-as}\left(N+1-a\right)\left(\left(a-1\right)b\cosh ab + \left(a-1\right)s\sinh ab\right) \end{bmatrix}}{s^2 - b^2}. \qquad (14)$$

IV. RESULTS AND DISCUSSIONS

All the examples considering $N=4$ or $N=5$. These results can be calculated considering for any value of N. The results can be extended to complex variables. The real and imaginary parts of the function will be obtained. The formula can be proved in the similar manner. The elementary functions using Kekre's function has been evaluated applying Laplace transforms over it. At the end of examples the generalized representation of the Laplace transforms of Kekre's function is formulated.

V. CONCLUSION

Kekre's function has been used in application to image processing and other computer engineering applications. This paper shows mathematical interpretation of Kekre's function, such that even Mathematicians can use it efficiently. Results are displayed with their calculations and process of the existence of Kekre's function.

VI. FUTURE SCOPE

This evaluations and observation done by the author in this work can help researchers for the elaborate study in this direction. Evaluation and analysis can be done for higher orders. Continuous transforms of such functions can be studied. Applications to different fields of engineering can fulfill the introduction of such function and its mathematical concept. Table for all the Laplace transforms to Kekre's function can be calculated.

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BIOGRAPHY

Dr. H. B. Kekre has received B.E (Hons.) in Telecomm. Engineering from Jabalpur University in 1958 M. Tech (Industrial Electronics) from IIT Bombay in 1960 M. S. Engg (Electrical Engg.) from University of Ottawa Canada in 1965 and Ph.D. (System Identification) from IIT Bombay in 1970. He has worked as Faculty of Electrical Engg.and then HOD Computer Science and Engg. at IIT Bombay. After serving IIT for 35 years he retired in 1995. After retirement from IIT for 13 years he was working as a professor and head in the Department of Computer Engg. and Vice Principal at Thadomal Shahani Engineering College Mumbai. Now he is Senior Professor at MPSTME SVKM's NMIMS University. He has guided 17 Ph. Ds more than 100 M.E./ M.Tech and several B. E./ B. Tech projects while in IIT and TSEC. His areas of interest are Digital Signal processing Image Processing and Computer Networking. He has more than 450 papers in National / International Journals and Conferences to his credit. He was Senior Member of IEEE. Presently He is Fellow of IETE Life Member of ISTE and Senior Member of International Association of Computer Science and Information Technology (IACSIT). Recently fifteen students working under his guidance have received best paper awards. Currently eight research scholars working under his guidance have been awarded Ph. D. by NMIMS (Deemed to be University). At present eight research scholars are pursuing Ph.D. program under his guidance.

Dr. V. R. Lakshmi Gorty has overall eighteen years service. Initially she worked with in Engineering Colleges under Mumbai University and now at SVKM's NMIMS University, MPSTME. She has done her Ph.D. from University of Pune. She has attended many seminars and workshops. She published twenty seven papers at national and international journals and conferences. She has been a resource person for MATLAB in state and national level and visited many colleges with this Performa. She is member of many professional bodies like IAIAM, ISTE, INS and IMS. She is also Congress Member of IAENG. She was the co-chair of ICTSM (International Conference) 2011 held at SVKM's NMIMS University, MPSTME. She worked as an editor of Springer series, where the selected papers of peer reviewed were published. She worked coordinator of the International conference ICATE 2013, sponsored by IEEE X-plore digital library. She is editor of Indian journal of science, engineering & technology management, approved with an ISSN 0975-525 X, Techno Path (National Journal) since its first issue (vol. I), January 2009.