

```

ln[*]:= << c:\femm42\mathfemm\mathfemm.m
MathFEMM loaded at Sun 17 Apr 2022 21:17:50

ln[*]:= OpenFEMM[1];

ln[*]:= myAWG = 20;
myFill = 0.5;
myKi = 0.26;
myKc = 398;
myKp = 1;

ln[*]:= c = 0.0254 * 10^6;

ln[*]:= dw[awg_] := (1 / 200) * 92^((36 - awg) / 39)

ln[*]:= myKw[kc_, ki_, R_, d_] :=
ki (2 kc R^2 + (2 R d + d^2) (kc + ki)) / (2 ki R^2 + (2 R d + d^2) (kc + ki))

ln[*]:= myKe[kc_, ki_, kp_, R_, d_, vc_] := Module[{kw, vw}, kw = myKw[kc, ki, R, d];
vw = vc * ((R + d) / R)^2;
kp * (kp * (1 - vw) + kw * (1 + vw)) / (kp * (1 + vw) + kw * (1 - vw))]

ln[*]:= MaxFill[awg_] := Module[{R, d},
R = (1 / 2) * dw[awg];
d = (28.3357 - 0.250092 * awg - (0.133567 * awg)^2 + (0.0623628 * awg)^3) / (0.0254 * 10^6);

$$\frac{\pi R^2}{2 \sqrt{3} (d + R)^2}$$

]

ln[*]:= GetKe[awg_, vc_, kc_, ki_, kp_] :=
Module[{R, d, Rtot, w, Inch, xm, F, G, femmKe, Ke, Thi, Tlo, mesh},
R = (1 / 2) * dw[awg];
d = (28.3357 - 0.250092 * awg - (0.133567 * awg)^2 + (0.0623628 * awg)^3) / (0.0254 * 10^6);
Rtot = R + d;
w = Sqrt[Pi * R^2 / (2 Sqrt[3] vc)];
Inch = 0.0254;
Thi = 1;
Tlo = 0;
mesh = d;
NewDocument[2];

HIDrawArc[R, 0, 0, R, 90, 1];
HIDrawArc[Rtot, 0, 0, Rtot, 90, 1];
HIDrawArc[Sqrt[3] * w - R, w, Sqrt[3] * w, w - R, 90, 1];
HIDrawArc[Sqrt[3] * w - Rtot, w, Sqrt[3] * w, w - Rtot, 90, 1];
HIDrawRectangle[0, 0, Sqrt[3] * w, w];

HIAddMaterial["Kc", kc];
HIAddMaterial["Ki", ki];

```

```

HIAddMaterial["Kp", kp];

xm = R / 2;
HIAddBlockLabel[xm, xm];
HIAddBlockLabel[Sqrt[3] * w - xm, w - xm];
HISelectLabel[xm, xm];
HISelectLabel[Sqrt[3] * w - xm, w - xm];
HISetBlockProp["Kc", 0, mesh, 0];
HIClearSelected[];

xm = (R + d / 2) / Sqrt[2];
HIAddBlockLabel[Sqrt[3] * w - xm, w - xm];
HIAddBlockLabel[xm, xm];
HISelectLabel[xm, xm];
HISelectLabel[Sqrt[3] * w - xm, w - xm];
HISetBlockProp["Ki", 0, mesh, 0];
HIClearSelected[];

HIAddBlockLabel[Sqrt[3] * w / 2, w / 2];
HISelectLabel[Sqrt[3] * w / 2, w / 2];
HISetBlockProp["Kp", 0, mesh, 0];
HIClearSelected[];

HIAddBoundProp["Thi", 0, Thi];
HISelectSegment[R / 2, w];
HISelectSegment[Sqrt[3] * w - R - d / 2, w];
HISelectSegment[Sqrt[3] * w - R / 2, w];
HISetSegmentProp["Thi", 0, 1, 0, 0, "<None>"];
HIClearSelected[];

HIAddBoundProp["Tlo", 0, Tlo];
HISelectSegment[R / 2, 0];
HISelectSegment[R + d / 2, 0];
HISelectSegment[Sqrt[3] * w - R / 2, 0];
HISetSegmentProp["Tlo", 0, 1, 0, 0, "<None>"];
HIClearSelected[];

HISaveAs["c:\\temp\\temp.feh"] × HIANalyze[1];
HILoadSolution[];
HOGroupSelectBlock[0];
F = HOBLOCKIntegral[3];
G = (Tlo - Thi) / (w * Inch);
femmKe = F[[2]] / G;
Ke = myKe[kc, ki, kp, R, d, vc];
HOClose[];
HIClose[];
{Ke, femmKe}

```

```
In[ ]:= Table[k, {k, 14, 50, 6}]
```

```
Out[ ]:= {14, 20, 26, 32, 38, 44, 50}
```

```
In[ ]:= myData = {};
```

```
For[awg = 14, awg ≤ 50, awg += 6,
```

```
z = {};
```

```
Print[awg];
```

```
For[fill = 0.1, fill < MaxFill[awg], fill += 0.01,
```

```
z = Append[z, Join[{fill}, GetKe[awg, fill, myKc, myKi, myKp]]]
```

```
];
```

```
myData = Append[myData, z]
```

```
]
```

```
14
```

```
20
```

```
26
```

```
32
```

```
38
```

```
44
```

```
50
```

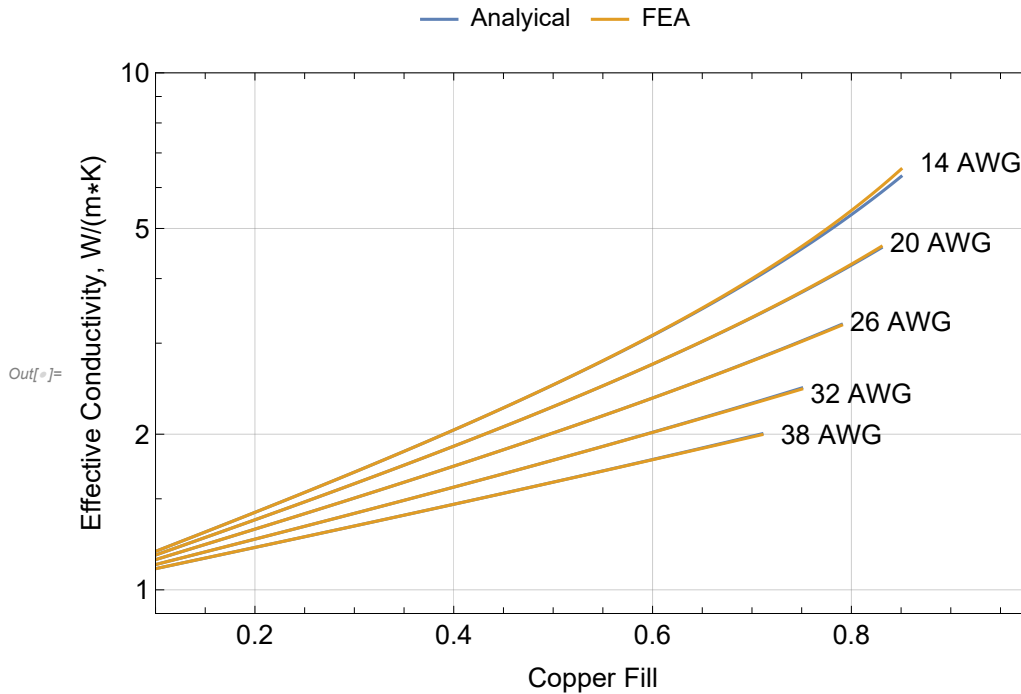
```
In[ ]:= u = {{1, 0}, {0, 1}, {0, 0}};
```

```
v = {{1, 0}, {0, 0}, {0, 1}};
```

```

In[ ]:= Show[ListLogPlot[{myData[[1]].u, myData[[1]].v}, Joined → True,
  Frame → True, GridLines → Automatic, PlotRange → {{0.1, 0.98}, {0.9, 10}},
  ImageSize → 500, BaseStyle → {FontFamily → "Arial", FontSize → 14},
  PlotLegends → Placed[{"Analytical", "FEA"}, Above],
  FrameLabel → {"Copper Fill", "Effective Conductivity, W/(m*K)"},
ListLogPlot[{myData[[2]].u, myData[[2]].v},
  Joined → True, Frame → True, PlotRange → {{0.1, 0.98}, {0.9, 10}},
  ImageSize → 500, BaseStyle → {FontFamily → "Arial", FontSize → 14},
  FrameLabel → {"Copper Fill", "Effective Conductivity, W/(m*K)"},
ListLogPlot[{myData[[3]].u, myData[[3]].v},
  Joined → True, Frame → True, PlotRange → {{0.1, 0.98}, {0.9, 10}},
  ImageSize → 500, BaseStyle → {FontFamily → "Arial", FontSize → 14},
  FrameLabel → {"Copper Fill", "Effective Conductivity, W/(m*K)"},
ListLogPlot[{myData[[4]].u, myData[[4]].v},
  Joined → True, Frame → True, PlotRange → {{0.1, 0.98}, {0.9, 10}},
  ImageSize → 500, BaseStyle → {FontFamily → "Arial", FontSize → 14},
  FrameLabel → {"Copper Fill", "Effective Conductivity, W/(m*K)"},
ListLogPlot[{myData[[5]].u, myData[[5]].v},
  Joined → True, Frame → True, PlotRange → {{0.1, 0.98}, {0.9, 10}},
  ImageSize → 500, BaseStyle → {FontFamily → "Arial", FontSize → 14},
  FrameLabel → {"Copper Fill", "Effective Conductivity, W/(m*K)"},
Graphics[{Text["38 AWG", {0.78, Log[2]}],
  Text["32 AWG", {0.81, Log[2.4]}],
  Text["26 AWG", {0.85, Log[3.3]}],
  Text["20 AWG", {0.89, Log[4.7]}],
  Text["14 AWG", {0.92, Log[6.7]}]
}]
]

```



```
In[ ]:= X = 100 * Flatten[Table[(myData[[k]].{0, -1, 1}) / (myData[[k]].{0, 0, 1}), {k, 1, 7}]]
```

```
Out[ ]:= {0.000300748, 0.00103122, 0.00135354, 0.00175755, 0.00193181, 0.00200376, 0.00220778,
0.0023563, 0.00247354, 0.00277061, 0.00283116, 0.00305383, 0.00320394, 0.00347525,
0.00358298, 0.00389792, 0.0041439, 0.00432715, 0.00471468, 0.00510145, 0.00550268,
0.00599139, 0.0065894, 0.00706885, 0.00782772, 0.00865209, 0.00938465, 0.0106109,
0.0117303, 0.0132243, 0.0148884, 0.0166055, 0.0190237, 0.0212782, 0.0240923, 0.0274096,
0.0313115, 0.035662, 0.0407673, 0.0462596, 0.052458, 0.0597421, 0.067762, 0.0772438,
0.0878905, 0.0998151, 0.113439, 0.128757, 0.145925, 0.165007, 0.186828, 0.211198,
0.238377, 0.268813, 0.30292, 0.340208, 0.382792, 0.429887, 0.482731, 0.541714,
0.607678, 0.680169, 0.762128, 0.852852, 0.953914, 1.06766, 1.19209, 1.33128, 1.48738,
1.66143, 1.85411, 2.06995, 2.31093, 2.58085, 2.88114, 3.21709, 0.00362471, 0.00398111,
0.00432484, 0.00479752, 0.00509922, 0.00545095, 0.0058509, 0.00633135, 0.00672537,
0.00715895, 0.00754402, 0.00798991, 0.00843589, 0.008852489, 0.00897338, 0.0090209,
0.00898052, 0.00919718, 0.00927077, 0.00904215, 0.00951003, 0.00976161, 0.00982072,
0.0101649, 0.0105001, 0.0105751, 0.0106823, 0.0111865, 0.0114658, 0.0118882, 0.0119921,
0.0126023, 0.0132806, 0.0141655, 0.0153239, 0.015742, 0.0169082, 0.0181566, 0.0196869,
0.021083, 0.0226147, 0.0246337, 0.0270032, 0.0291955, 0.0325117, 0.0353892, 0.0390938,
0.0429326, 0.0475258, 0.0526658, 0.0583751, 0.064745, 0.0711865, 0.0795299, 0.0884988,
0.0979383, 0.108397, 0.12039, 0.133246, 0.148308, 0.164419, 0.182665, 0.202267, 0.224764,
0.248227, 0.275379, 0.304837, 0.337293, 0.373154, 0.411907, 0.455623, 0.503803,
0.556627, 0.612754, 0.00566501, 0.00604884, 0.00583981, 0.00582352, 0.00586559,
0.00609023, 0.00627231, 0.00644334, 0.00637859, 0.0065472, 0.00667701, 0.00674806,
0.00680148, 0.006877, 0.00681607, 0.00717384, 0.007223, 0.00722469, 0.00720464,
0.0074089, 0.0072576, 0.00723943, 0.00736937, 0.00713802, 0.00713812, 0.00714616,
0.00699552, 0.00692417, 0.00655702, 0.00625232, 0.00605944, 0.00559243, 0.00520379,
0.0045229, 0.00388336, 0.00306388, 0.00208753, 0.00102049, -0.000229274, -0.00156827,
```

-0.00328815, -0.00512669, -0.00743877, -0.0096941, -0.0121978, -0.0155921, -0.0191086,
 -0.0228288, -0.0273671, -0.0326649, -0.0376894, -0.0444818, -0.0509622, -0.0587044,
 -0.0674329, -0.0767211, -0.0873779, -0.0993436, -0.111684, -0.126304, -0.142083,
 -0.159361, -0.178574, -0.199649, -0.22304, -0.248846, -0.276837, -0.307907, -0.341958,
 -0.379937, 0.00434417, 0.00456947, 0.00433736, 0.00455312, 0.00461983, 0.00313439,
 0.00444449, 0.00524537, 0.0052949, 0.00542847, 0.00552806, 0.00567608, 0.00575134,
 0.00594137, 0.0059006, 0.00605098, 0.00615742, 0.00629773, 0.00627339, 0.00629298,
 0.00628136, 0.00623154, 0.0060382, 0.00598062, 0.00583445, 0.00543726, 0.00521283,
 0.00471569, 0.00419439, 0.00358292, 0.00279198, 0.00191574, 0.000684167, -0.000414664,
 -0.00190169, -0.00376809, -0.00575348, -0.00813432, -0.0108117, -0.0136883, -0.0169953,
 -0.0210472, -0.0257304, -0.0305466, -0.0364069, -0.0428909, -0.0502848, -0.0585666,
 -0.0675108, -0.0772215, -0.0887281, -0.101215, -0.115381, -0.131017, -0.148215,
 -0.167514, -0.18872, -0.212211, -0.238479, -0.267463, -0.299675, -0.334533, -0.373379,
 -0.416877, -0.465135, -0.519328, 0.00399781, 0.00374506, 0.00415189, 0.00425804,
 0.0047411, 0.00446737, 0.00513774, 0.00497935, 0.00536843, 0.0058368, 0.00563322,
 0.00583432, 0.00608354, 0.00523113, 0.00676867, 0.00497301, 0.00678578, 0.00661758,
 0.00689381, 0.00764173, 0.00731418, 0.00684796, 0.00693173, 0.00717146, 0.00656351,
 0.00619278, 0.00624335, 0.00567082, 0.00487077, 0.00430892, 0.00335962, 0.00238299,
 0.00129443, -0.000445413, -0.00201534, -0.00428977, -0.00630415, -0.00914685,
 -0.0125162, -0.0158133, -0.0195832, -0.0243032, -0.0294035, -0.035483, -0.0425419,
 -0.0499217, -0.0582773, -0.067487, -0.0780562, -0.0898389, -0.103231, -0.117881,
 -0.133961, -0.152433, -0.172977, -0.195649, -0.220398, -0.248242, -0.279529, -0.314417,
 -0.352818, -0.396706, 0.00393193, 0.00423837, 0.00442263, 0.00476366, 0.00489331,
 0.00445941, 0.00505636, 0.0052587, 0.00570306, 0.00371352, 0.00613692, 0.00632189,
 0.00646388, 0.00658547, 0.00672386, 0.00711849, 0.00723937, 0.00722693, 0.00749184,
 0.00739886, 0.00769258, 0.0078895, 0.00733586, 0.00695152, 0.00707586, 0.00669851,
 0.0064487, 0.00598324, 0.00541178, 0.00444182, 0.00388255, 0.00293321, 0.00164816,
 0.000103535, -0.00162929, -0.00377633, -0.00629976, -0.00877235, -0.0121705,
 -0.01542, -0.0197723, -0.0246494, -0.0300707, -0.0356442, -0.0427899, -0.0500661,
 -0.0591934, -0.0682851, -0.0790956, -0.0910387, -0.104252, -0.119288, -0.135501,
 -0.154477, -0.174583, -0.197665, -0.223105, -0.251605, -0.283744, -0.320146,
 -0.361493, 0.0040768, 0.00462629, 0.00429712, 0.00443528, 0.00683125, 0.00304283,
 0.00552997, 0.00560665, 0.00548356, 0.00566833, 0.00594401, 0.00615003, 0.0061976,
 0.00649336, 0.00657398, 0.00643085, 0.00689708, 0.00696804, 0.00724344, 0.0071578,
 0.0072539, 0.00714544, 0.00698627, 0.00936066, 0.0069852, 0.00672694, 0.00639909,
 0.00589917, 0.00920653, 0.00462107, 0.00422188, 0.00287149, 0.00142466, -0.000232526,
 -0.0019778, -0.00417644, -0.00594409, -0.00871206, -0.0120082, -0.0155554, -0.0195115,
 -0.0243951, -0.0294556, -0.03534, -0.0418181, -0.049865, -0.0580636, -0.0677132,
 -0.077902, -0.0893653, -0.102498, -0.117177, -0.133574, -0.151982, -0.171304,
 -0.193699, -0.218661, -0.246845, -0.277204, -0.311485, -0.349118, -0.391661}

In[*]:= **Max[X]**

Out[*]:= 3.21709

In[*]:= **Sqrt[X.X / Length[X]]**

Out[*]:= 0.351863