BY HOWARD JOHNSON, PhD

Twisted impedance

liver Kent of Muirhead Aerospace Ltd recently comment-
ed on my formula for twisted-pair line impedance (**Figure
1**). "I am using coated wire with 1.3-mm outer diameter and
0.95-mm inner diameter," Kent wrote. "The insulation is
PTFE [polytetrafluoroethylene] with a dielectric con-
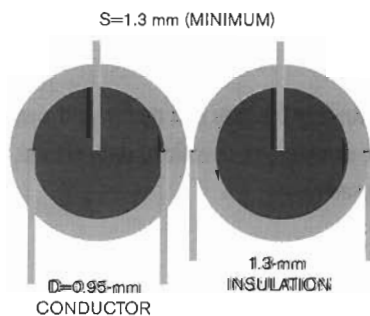stant, ϵ_R, of 2. Your formula contains the term $\ln((2S)/D)$.
That term gives a negative value when twice the wire separation over the

conductor diameter is less than 1. I ap-
preciate any help or advice you could
give regarding this matter."

Kent may be interpreting the spac-
ing as the distance between the wires.
I don't. In my system of units, I define
the wire spacing from center to cen-
ter (**Figure 1**). The spacing therefore
always exceeds the diameter, so the
ratio 2S/D always exceeds 2, and the
logarithm cannot go negative.

The simple approximation in **Fig-
ure 1** is not perfect. In the real world,
if you could press the wires closer and
closer together, the impedance would
plummet to zero. The approxima-
tion doesn't show that result. In the
equation, when the metallic conduc-

tors touch with S equal to D, the term
$\ln((2S)/D)$ gives a minimum value of
$\ln(2)=0.693$, which is incorrect.

I derived the approximation for use
only in cases with a reasonably large
spacing between wires, in which you
may assume a uniform distribution of
current around the periphery of each
conductor. In a situation with close-
ly spaced wires, the "proximity effect"
generates a nonuniform distribution of
current, with the greatest preponder-
ance of current occurring on the in-
side-facing surfaces of the two conduc-
tors. Because the approximation does
not take into account the proximity
effect, it overestimates the impedance
in situations with closely spaced wires.

For ordinary twisted-pair wires in a
100Ω configuration, the ratio S/D is
approximately 2. The redistribution of
current due to the proximity effect in
that case remains fairly modest, pro-
ducing only a 15% increase in effective
resistance and a negligible effect on
impedance. In Kent's case, the proxim-
ity effect will be more noticeable.

Another difficulty with the approx-
imation involves the concept of "ef-
fective dielectric constant." The fields
surrounding the wires exist partly in
the dielectric insulation and partly in
the air surrounding the whole config-
uration. The effective dielectric con-
stant, therefore, lies between that
of air, which is 1, and that of PTFE,
which is 2. The exact value takes in-
to account the relative proportions of
field energy in those two substances.

Unfortunately, unless you have a
2-D field solver handy, you can't know
in advance the relative proportions
of field strength in air and insulation,
so you can't compute, from first prin-
ciples, the effective dielectric con-
stant. In that case, you should mea-
sure the velocity of propagation on a
sample cable and use that measure-
ment to determine the effective di-
electric constant. The relation of ve-
locity to dielectric constant is: veloc-
ity (m/sec)=speed of light (m/sec)/
$\sqrt{\epsilon_{R(EFFECTIVE)}}$.

Once you have obtained a value for
the effective dielectric constant, plug
that value into the approximation to
determine the expected impedance
and, more important, the expected
change in impedance with changes in
geometry. The effective dielectric con-
stant does not vary much with small
changes in the wire geometry. **EDN**

*Howard Johnson, PhD, of Signal Con-
sulting, frequently conducts technical
workshops for digital engineers at Oxford
University and other sites worldwide.
Visit his Web site at www.sigcon.com or
e-mail him at howie03@sigcon.com.*

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S=1.3 mm (MINIMUM)

D=0.95-mm
CONDUCTOR

1.3-mm
INSULATION

$$Z_{DIFF} \approx \frac{120}{\sqrt{\epsilon_R}} \ln\left(\frac{2S}{D}\right),$$

WHERE Z IS THE DIFFERENTIAL IMPED-
ANCE, S IS THE CENTER-TO-CENTER SPAC-
ING, D IS THE DIAMETER, S ALWAYS EX-
CEEDS D, AND 2S/D ALWAYS EXCEEDS D.

EXAMPLE:

$$\frac{2S}{D} = \frac{2(1.3)}{0.95} = 2.736.$$

Figure 1 The differential impedance of this twisted-pair configuration depends on
the ratio of spacing, S, to conductor diameter, D.